PB81-172421

Occupational Exposure to Ionizing Radiation in the United States A Comprehensive Summary for the Year 1975

(U.S.) Office of Radiation Programs
Washington, DC

Nov 80

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA 520/4-80-001

2.

3. RECIPIENT'S ACCESSION NO. PB81 172421

4. TITLE AND SUBTITLE
Occupational Exposure to Ionizing Radiation in the United States: A Comprehensive Summary for the Year 1975

5. REPORT DATE November 1980

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
John R. Cook and DeVaughn R. Nelson

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Criteria and Standards Division
Office of Radiation Programs
U.S. Environmental Protection Agency
ANR-460 Washington, D.C. 20460

10. PROGRAM ELEMENT NO.

11. CONTRACT/GRANT NO.

12. SPONSORING AGENCY NAME AND ADDRESS
Same as Above

13. TYPE OF REPORT AND PERIOD COVERED Final

14. SPONSORING AGENCY CODE 200/03

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report summarizes the results of a study of 1975 occupational exposures to ionizing radiation in the United States. Exposure data for all workers exposed to radiation are unavailable,so many of our results are estimates based on extrapolation of partial data that may not be representative of some groups of workers. Our primary findings are: 1.About 1.1 million United States workers were exposed to ionizing radiation in 1975. About 370,000 received measurable occupational doses; 2.The collective dose to the work force was nearly 130,000 person-rems. The approximately 5.5% of the work force that received more than 500 mrem accounted for about 75% of this collective dose; 3. The average annual dose to all workers was 120 mrem; for workers with measurable doses, it was 350 mrem; and for workers receiving more than 500 mrem, it was 1,600 mrem; and 4. About 67% of the work force received less-than-measurable doses; about 95% received doses of 500 mrem or less; and about 0.15% received doses exceeding 5 rem. Many other findings and observations are included.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
	Exposure Ionizing Radiation Workers Occupation 1975 United States	

18. DISTRIBUTION STATEMENT Release Unlimited	**19. SECURITY CLASS** *(This Report)* Unclassified	**21. NO. OF PAGES** 152
	20. SECURITY CLASS *(This page)* Unclassified	**22. PRICE**

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

United States
Environmental Protection
Agency

Office of
Radiation Programs
Washington DC 20460

November 1980
EPA 520/4-80-001

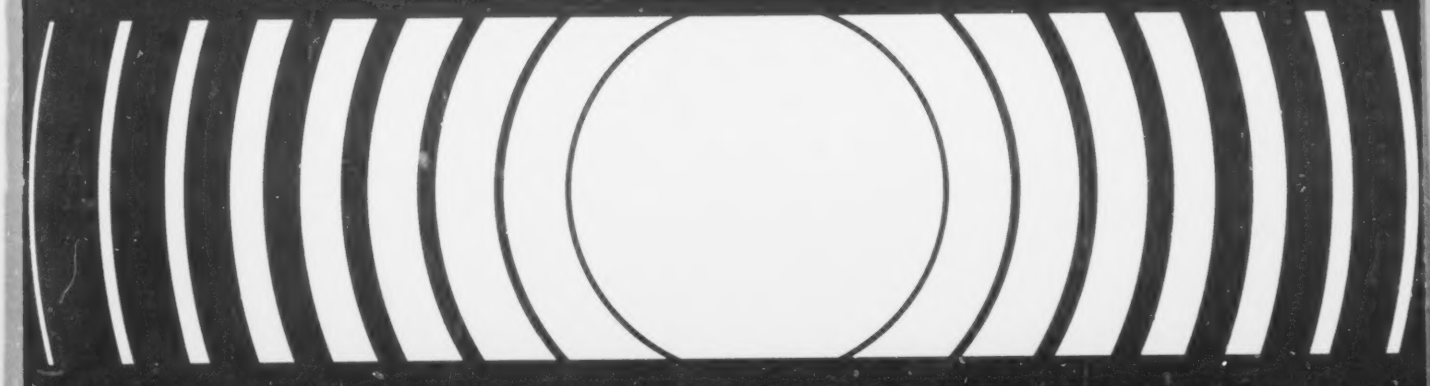
PB81-172421

Radiation

EPA

Occupational Exposure to Ionizing Radiation in the United States:

A Comprehensive Summary for the Year 1975



REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

OCCUPATIONAL EXPOSURE TO IONIZING RADIATION IN THE UNITED STATES:

A Comprehensive Summary for the Year 1975

John R. Cook
DeVaughn R. Nelson

November 1980

General Radiation Standards Branch
Criteria and Standards Division
Office of Radiation Programs
U.S. Environmental Protection Agency

FOREWORD

The Environmental Protection Agency's Office of Radiation Programs has a national program to evaluate exposure to ionizing and nonionizing radiation, to develop radiation standards and guidance to Federal agencies, to protect the public health and safety, and to assure environmental quality. The responsibility to formulate Federal guidance for occupational exposure derives from Executive Order 10831 and Public Law 86-373 (42 USC 2021(h)), which charge the Administrator of the Environmental Protection Agency to "advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with States."

The number of workers exposed to ionizing radiation has increased significantly since existing Federal Radiation Protection Guidance for occupational exposure was issued in 1960. This report provides a comprehensive summary of exposures of workers for the year 1975, and was prepared in support of a program to update and revise that guidance.

The Office of Radiation Programs would like to know of any errors or omissions and of additional sources of information. All comments and suggestions for improvements in future reports on this subject are welcome.

PREFACE

The Environmental Protection Agency is reviewing the Federal Radiation Protection Guidance for occupational exposure to ionizing radiation. As part of this review, we recognized the need for comprehensive, reliable information on numbers of workers and their doses for various occupations using radiation sources. Therefore, early in 1976, we undertook a program to summarize 1975 occupational exposure to ionizing radiation in the United States.

We found that existing information varies widely. Monitoring and recordkeeping practices differ considerably among occupations, industries, and regulatory agencies. Our exposure estimates for several occupational subcategories are quite uncertain because the data are limited. Small data samples may not be representative, because individual dosimeter readings can have significant errors. We believe, however, that average doses for the work force as a whole, and its major subcategories, are based on significant enough numbers of monitored workers to provide a reliable assessment.

We have the most confidence in our estimates for specific types of workers where government agencies require, or maintain themselves, comprehensive personnel dosimetry record systems. For completeness, however, we have included projections for all types of workers, even when complete data is unavailable. Similarly, we projected worker distribution and exposure by age and sex from available, but incomplete data.

This report omits two relatively small groups of workers: uranium miners and other miners exposed to radon gas and its decay products, and airline workers exposed to cosmic radiation. Finally, we have summarized whole-body exposures only, since there are insufficient data to generate summaries for partial-body, internal, and extremity exposures. With these qualifications, we believe that this report summarizes 1975 occupational exposure to ionizing radiation.

* * *

We are indebted to the many people who helped with this project. We especially thank Sanford C. Cohen of Teknekron Research, Inc., who supervised a prime contract report that was a foundation for this study.

The following officials of Federal agencies and State departments of health supplied exposure records and licensee or registrant listings essential to the report:

Lt. Col. Johan Bayer, Air Force; Col. Vandy Miller, Army; Caleb Kincaid, Bureau of Radiologial Health (Department of Health and Social Services), Carol Woods, Energy Research and Development Administration (now the Department of Energy); Horace P. Richardson, Mining Enforcement and Safety Administration (now Mine Safety and Health Administration); Gene Proctor, National Aeronautics and Space Administration; Dr. Abraham Schwebel, National Bureau of Standards; Michael B. Musachio, National Institutes of Health; Cmdr. William M. Beckner, Navy; Barbara Brooks, Nuclear Regulatory Commission; and, for the States, Joseph O. Ward, California; Maurice E. Neuweg, Illinois; William H. Spell, Louisiana; Charles Flynn, Maryland; Eugene Fisher, New Jersey; Bill Condon, Fred Strinsa, Dr. F. J. Bradley and Dr. Leonard Solon, New York; James Wynd, Ohio; J. Donald McDonald, Pennsylvania; and Joseph M. Nanus, Texas.

Mr. Philip A. Cuny performed computer analyses of the occupational data, Ms. Jane Zabinski and Mr. Matthew Weinstein helped in the calculation of descriptive statistics and the preparation of tables and figures, and Ms. Amelia Manning and Mr. Avery Comarow edited the manuscript.

CONTENTS

Page

Foreword iii

Preface iv

Contents vii

Summary 1

I. INTRODUCTION 7

II. REVIEW OF PREVIOUS OCCUPATIONAL EXPOSURE INFORMATION 9
  A. Early Records and Studies of Workers Exposed to Radiation in the United States 9
  B. Growth in Exposure Reporting and Regulation 12

III. FACTORS IN OCCUPATIONAL EXPOSURE IN 1975 21
  A. Types of Exposure and Personnel Dosimeters 21
  B. Regulatory Authorities 22
    1. Federal 22
    2. State 26
    3. Indirect 27
  C. Monitoring and Reporting Requirements 28

IV. DATA SOURCES AND SUMMARY METHODS 31
  A. Data Sources 31
    1. Government 31
    2. Commercial 32
  B. Methods for Summarizing Data 35
  C. Radiation Work Force and Exposure Data 36

V. NATIONAL OCCUPATIONAL EXPOSURE SUMMARY FOR 1975 39
  A. Occupational Categories 39
  B. Results 39
    1. Composition of the Radiation Work Force 39
      a. Average dose considerations 44
      b. Distribution of work force and collective dose 45
      c. Dose range distributions 45
    2. Extrapolations by Ages and Sex for Major Occupational Categories 49
      a. Potentially exposed work force 49
      b. Collective dose 53
      c. Average whole-body doses 53
    3. Calculated Lifetime Doses 59

CONTENTS (continued)

Page

4. Average Dose for Established Dose Range Intervals 59
5. Contribution to Collective Dose from Doses Reported as Less Than Measurable 60
6. Extremity Exposures 64

VI. SOURCES OF ERROR AND UNCERTAINTY 65
A. Measurement Error 65
B. Dosimeter Misuse 67
C. Conclusion 67

REFERENCES 69

APPENDIX A - THE LIST METHOD A-1

APPENDIX B - THE CODE METHOD B-1

APPENDIX C - ANALYSIS OF MISCELLANEOUS CATEGORIES C-1

APPENDIX D - TABULATED SUMMARIES FROM FEDERAL AGENCIES D-1

APPENDIX E - COMMERCIAL EXTREMITY DATA E-1

TABLES

Table	Title	Page
1.	Distribution of Annual Whole-Body Exposures for AEC and AEC Contractor Personnel	11
2.	Occupational Exposure Summary for 1960	14
3.	State Radiological Health Programs	18
4.	Occupational Exposure Summary for 1970	19
5.	Major Regulatory Authorities for 1975 Occupational Exposures	24
6.	Summary of 1975 Occupational Exposure Data from Federal Agencies	33
7.	Occupational Categories and Subcategories used in this Report	40
8.	National Occupational Exposure Summary for 1975	42
9.	Distribution of the 1975 Radiation Work Force by Dose Range and Occupation	50
10.	Distribution of Workers by Age and Sex for Major Occupations	52
11.	Distribution of Whole-Body Collective Dose by Age and Sex for Major Occupations	54
12.	Distribution of Mean Whole-Body Dose by Age and Sex for Major Occupations	58
13.	Comparison of Two Collective Dose Estimates: Range Midpoints and Observed Means	61
14.	Estimated Contribution of Doses Reported as Less-Than-Measurable	63

FIGURES

Figure	Title	Page
1.	Radiation Exposure of Military and Civilian Personnel in the Naval Nuclear Propulsion Program	13
2.	Number of NRC Byproduct Licensees, 1960-1975	17
3.	Authorities for Radiation Protection of Workers	23
4.	Schematic Diagram of Work Force Segments and Exposure Data Sources Used in this Report	37
5.	Distribution of Radiation Work Force by Occupation	46
6.	Distribution of Collective Dose by Occupation	47
7.	Distribution of Whole-Body Dose for the Radiation Work Force	48
8.	Distribution of Collective Dose by Age and Sex for the Radiation Work Force	55
9.	Distribution of Collective Dose by Occupation, Age Group and Sex	56

SUMMARY

This report summarizes the results of a study of 1975 occupational exposures to ionizing radiation in the United States. Exposure data for all workers exposed to radiation are unavailable, so many of our results are estimates based on extrapolation of partial data that may not be representative of some groups of workers. We, in particular, caution against too much credence being given to the age and sex extrapolations.

Our primary findings are:

1. About 1.1 million United States workers were exposed to ionizing radiation in 1975. About 370,000 received measurable occupational doses. (Measurable here means that a dose was distinguishable from background dose for at least one reporting period during the year.)

2. The collective dose to the work force was nearly 130,000 person-rems. The approximately 5.5% of the work force that received more than 500 mrem accounted for about 75% of this collective dose.

3. The average annual dose to all workers was 120 mrem; for workers with measurable doses, it was 350 mrem; and for workers receiving more than 500 mrem, it was 1,600 mrem.

4. About 67% of the work force received less-than-measurable doses; about 95% received doses of 500 mrem or less; and about 0.15% received doses exceeding 5 rem.

5. Major occupational categories:

-- Workers in MEDICINE comprised 49% of the radiation work force; in INDUSTRY, 18%; in GOVERNMENT, 17%; in MISCELLANEOUS (transportation and education), 9%; and in the NUCLEAR FUEL CYCLE, 7%.

-- Workers in MEDICINE accounted for the largest share of the collective dose (40%), double the nearly equal shares for INDUSTRY (20%), the NUCLEAR FUEL CYCLE (19%), and the GOVERNMENT (18%).

6. Male and female workers:

-- The average dose to all male workers was more than twice that to all female workers.

-- Although male workers outnumber female workers 4-to-3, they receive 75% of the collective dose to the entire work force.

-- Of the total collective dose to female workers, 65% was received by women under the age of 30 and over 80% by women in MEDICINE.

We also make the following observations:

- From 1960 to 1975 the average annual growth rate of the U.S. population was 1.2%, while that of the radiation work force was about 6%.

- The degree of monitoring varied widely among occupational groups. For most Federal Agencies and for workers closely regulated by Federal agencies, such as the NUCLEAR FUEL CYCLE, almost all potentially exposed workers are monitored. On the other hand, we estimate that less than half the workers in MEDICINE (who number more than seven times those in the NUCLEAR FUEL CYCLE) are monitored.

- This report's average annual dose estimates for whole-body exposure may not be comparable or accurate for all workers. For example:

  - A personal monitoring device only records the dose it receives. Some occupational workers, notably medical, wear the monitoring device inside or outside a protective apron. The recorded dose may or may not approximate their whole-body dose.

  - About one-third of all monitored workers received a measurable dose. The two-thirds receiving a "less-than-measurable" dose were counted as receiving a zero dose.

- The age distribution of workers exposed to radiation is skewed toward younger workers. People under age 30 accounted for 48% of the work force exposed to radiation, but comprised only 37% of the total national work force.

- Exposures are different according to sex. Men under age 30 received 33% of the total collective dose, compared to 16% for women under age 30. However, average individual exposures were more than two times greater for young men, because there are more women than men under 30 in the work force exposed to radiation. Men under 30 averaged 180 mrem annually, compared to 70 mrem for women under 30.

Personnel dosimeters can provide accurate exposure information, but their performance varies widely. Their misapplication or intentional misuse can also result in mistakes. If a commercial dosimetry service does not correct them, the erroneous records remain in the data system. Using uncorrected exposure data leads to inaccurate projections of occupational exposure. We consider commercial data used in this

6

report less reliable than summaries obtained from Federal regulatory agencies. We believe that exposure data from the latter benefit from evaluation and corrections before the data are reported to a Federal agency. (See Chapter VII for detailed discussion.)

We did not fully analyze dosimeter errors or resolve uncertainties about numbers of workers in specific occupational categories. However, we estimate that actual values for the national summary statistics are probably within 30% of our results.

I. INTRODUCTION

The Federal Radiation Council (FRC) was established in 1959 "to advise the President with respect to radiation matters directly or indirectly affecting health." In a 1960 memorandum to President Eisenhower, the FRC recommended what is now the Federal Radiation Protection Guidance for occupational exposure to ionizing radiation (1).* This guidance provides the basis for present Federal regulations for occupational radiation protection. Reorganization Plan 3 of 1970 abolished the FRC and transferred its functions to the U.S. Environmental Protection Agency (EPA).

In 1974 EPA began a review of the current guidance on occupational exposure. As part of that review, we examined the magnitude and extent of occupational exposure in 1975 in the U.S. In this report, we provide our summarized analysis. We also discuss the growth of the radiation work force, the development of monitoring and reporting practices, the regulatory bodies involved, the regulatory requirements in effect in 1975, and the sources of data and methods we used. In Appendices A & B we describe in some detail the two different methods (List and Code) used to estimate average annual exposures and the size of different parts of the work force.

---

* References are on p.69.

We tried to use a minimum of new terminology. We introduced two terms, however, to differentiate major parts of the radiation work force: "total" and "exposed." "Total" workers means the actual or projected number of all workers potentially exposed to ionizing radiation. These workers, regardless of monitoring status, can be exposed beyond background levels on the job. "Exposed" workers means the actual or projected number of workers that received measurable exposure (occupational exposures greater than approximately 10 mrem). All "exposed" workers are not necessarily monitored for exposure. Section V.B. contains additional discussion of these points.

II. REVIEW OF PREVIOUS OCCUPATIONAL EXPOSURE INFORMATION

A substantial growth in uses of ionizing radiation has occurred in the United States since the late 1950's. There has been a corresponding increase in the size of the work force exposed to radiation.

The first year for which even crude estimates of numbers and doses were available for these workers was 1960 (2,3). The 1960 figures indicated that about 440,000 workers were potentially exposed to ionizing radiation. By 1970, the number of these workers grew to an estimated 775,000, an increase of about 80% in ten years (3). The estimated average annual dose per potentially exposed person remained about 200 mrem from 1960 to 1970.

There has been little monitoring of personnel exposure in some occupational categories. For example, 250,000 medical workers were estimated to be exposed to radiation in 1960, yet there were too few data available to estimate their average dose reliably (2). Data for many industrial workers were equally scarce. Workers in jobs in or actively regulated by the Federal government generally have had the best monitoring. Most other workers, especially those receiving relatively low-level exposures, generally have had little or no monitoring.

A. Early Records and Studies of Workers Exposed to Radiation in the United States

The Manhattan Engineering Project, created during World War II to develop an atomic bomb, generated most of the earliest recorded data for large numbers of workers potentially exposed to radiation in the United States. In 1946, the Atomic Energy Commission (AEC) was established by Congress to regulate and encourage the development of atomic energy and to assume responsibility for the Manhattan Project. In 1974, Congress split the AEC into the Nuclear Regulatory Commission (NRC) and the Energy Research and Development Administration (ERDA). In 1977 ERDA was merged with other agencies to form the Department of Energy (DOE).

Early in its existence the AEC began to monitor and maintain records on its workers and many others employed by contractors. It did not publish summaries of worker exposure until the late 1950's. AEC reports published in the 1960's focused on accidental exposures (4-11). The AEC later established a worker registry with information on overexposure incidents (12, 13). In the 1970's, they began to publish complete exposure summaries for AEC facilities, licensed nuclear power plants, and other licensees (14-20). NRC and ERDA separately continued publication of these detailed summaries (21-32) in 1974.

Table 1 summarizes whole-body exposures for AEC workers and employees of AEC contractors from 1947 to 1970 (33). As shown in the table, this work force increased from an average of 17,000 from 1947 to 1954 to a maximum of 138,000 during the next 15 years.

A thorough but small pilot study of occupational exposure to ionizing radiation at the Westinghouse Testing Reactor Facility was funded by the Public Health Service (PHS) in the early 1960's (34). The study included 2,300 individuals for the period 1950-63 and focused on record-keeping practices and usefulness of records for epidemiological studies. The report provided the first published summary of annual occupational exposures.

Table 1. DISTRIBUTION OF ANNUAL WHOLE-BODY EXPOSURES FOR AEC EMPLOYEES AND EMPLOYEES OF AEC CONTRACTORS*

	Number of Workers Exposed					
Years	0-1 rem	1-5 rem	5-10 rem	10-15 rem	15+ rem	Total
1947-54	130,128	5,311	284	32	6	135,761
1955	56,708	3,157	285	41	1	60,192
1956	38,225	2,312	100	4	3	40,644
1957	45,510	2,424	83	5	1	48,023
1958	59,455	6,271	159	10	12	65,907
1959	71,600	3,912	66	2	1	75,581
1960	77,522	4,629	41	2	1	82,195
1961	90,651	5,174	40	3	8	95,876
1962	122,437	5,707	113	0	8	128,265
1963	107,786	5,472	80	0	1	113,339
1964	122,711	6,157	86	11	0	128,965
1965	128,360	6,671	175	8	0	135,214
1966	130,552	7,218	167	0	2	137,939
1967	101,764	6,513	108	1	0	108,386
1968	103,206	4,776	4	0	0	107,986
1969	98,625	4,288	4	1	0	102,918
1970	92,185	4,464	12	0	0	96,661

---

*Source: Operational Accidents and Radiation Exposure Experience Within the United States Atomic Energy Commission, WASH 1192, Fall 1971 (33).

A 1979 Naval Sea Systems Command report summarizes occupational radiation exposure from U.S. Naval nuclear propulsion plants and their support facilities for the period 1954-1978 (the first nuclear-power ship went to sea in January 1955) (35). Since 1966, there has been a significant and steady fall in collective radiation dose (man-rems/year), in spite of an ever-increasing number of ships in operation (see Figure 1).

We can compile a rough general exposure summary (limited to certain segments of the work force) for 1960 (see Table 2). It combines data from Federal agencies and estimates made by the Federal Radiation Council (FRC). The data include workers monitored for convenience as part of security badging who did not receive measurable doses (military and AEC personnel, for example). The FRC estimated that in 1960 there were about 250,000 and 50,000 radiation workers in medicine and general industry, respectively (2), but gave no exposure estimates for them.

B. Growth in Radiation Exposure Reporting and Regulatory Activities

The number of x-ray generators, artificially-produced radionuclides, nuclear power reactors, and high-voltage accelerators have greatly increased in the last several decades, raising the number of workers potentially exposed to ionizing radiation.

Exposure data reported to and by the AEC cover principally that part of the work force using radionuclides. Information from AEC licensees, however, helps to gauge the growth of the entire work force and to review related state activities (4-32). In 1958, Congress amended the Atomic Energy Act to permit states to regulate certain radioactive byproduct

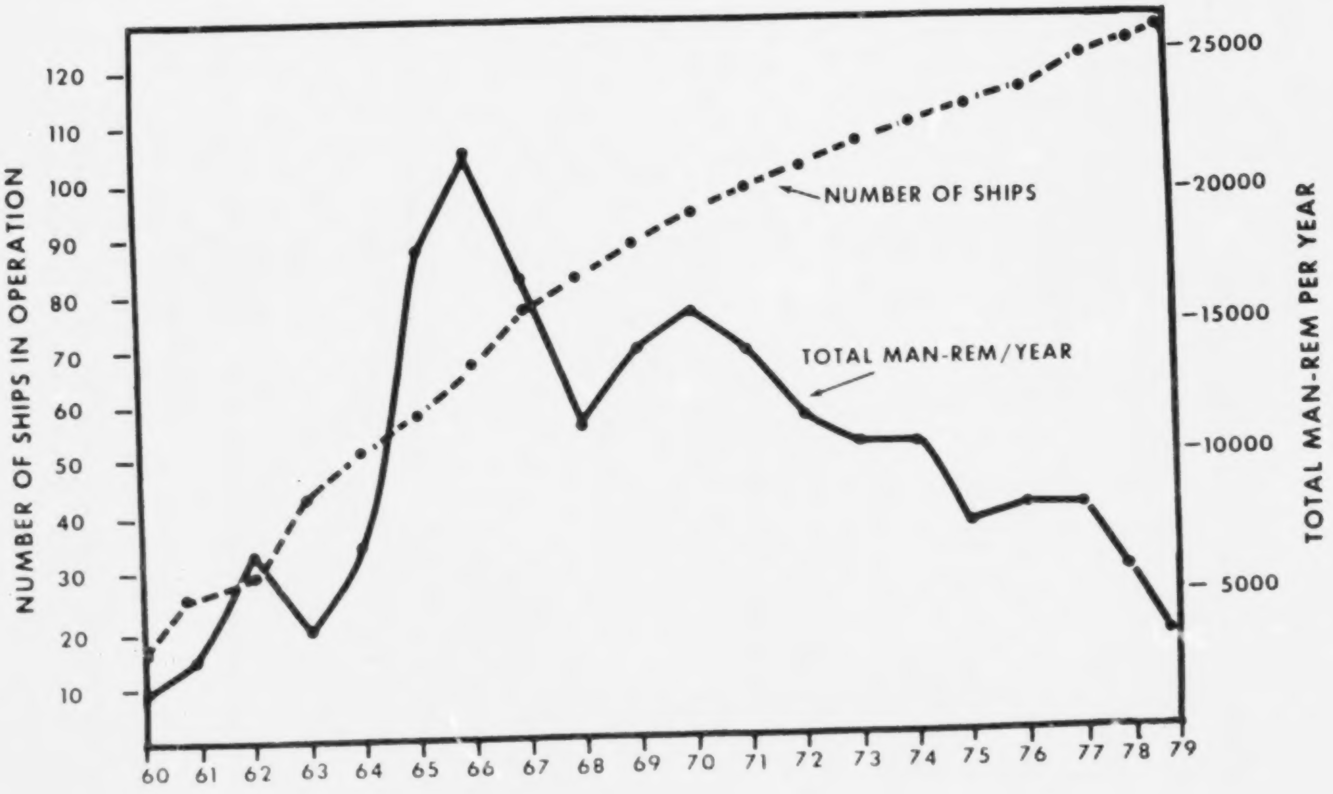


Figure 1. TOTAL RADIATION EXPOSURE RECEIVED BY MILITARY AND CIVILIAN PERSONNEL IN THE NAVAL NUCLEAR PROPULSION PROGRAM 1960-1979 (35)

Table 2. OCCUPATIONAL EXPOSURE SUMMARY FOR 1960

Occupational Group	Number of Persons	Mean Whole-Body Dose (millirem)*
A. Federal Agencies		
U.S. Air Force[1]	6,800	30
U.S. Army[2]	16,400	30
U.S. Navy[3,4,5]		
1. Nuclear Propulsion Program		
a. government	4,685	230
b. contractor	10,394	50
2. Non-Nuclear Navy (government)	7,420	220
Atomic Energy Commission and Contractors (some Federal-mostly contractor employees)[6]	82,195	220
Bureau of Radiological Health (HEW)[7]	1,500	-
Mining Enforcement and Safety Administration (privately employed uranium miners)[8]	5,800	-
National Aeronautics and Space Administration[9]	200	-
National Bureau of Standards[10]	100	-
National Institutes of Health[11]	530	-
SUBTOTAL, Federal Agencies	136,024	170**
B. Healing Arts[12,13]	250,000	
C. Industry[12]	50,000	
TOTAL	436,024	

*Values for mean whole-body dose are rounded to the nearest 10 millirem.
**Mean whole-body dose for AEC and Department of Defense personnel and contractor personnel.

Table 2. (Continued)

Sources of Information:

1. Nelson, Maj. Robert, U.S. Air Force, Brook AFB, Personal communication, February 6, 1980, and Ricci, Capt. John, U.S. Air Force, Brook AFB, Personal communication, May 14, 1979

2. Wangemann, Col. Robert, U.S. Army, Office of the Surgeon General, Personal communication based on best available information, February 13, 1980.

3. Miles, M.E. and W.R., Kindley, "Occupational Radiation Exposure from U.S. Naval Nuclear Propulsion Plants and Their Support Facilities," Naval Sea Systems Command, Department of the Navy, Report NT-78-2, February 1979.

4. Arentzen, Vice Admiral W.P., The Surgeon General of the Navy, Personal communication, January 22, 1979.

5. Kindley, W.R., Personal communications, September 27, 1979 and February 4, 1980.

6. "Operational Accidents and Radiation Exposure Experience, 1943-1970," Division of Operational Safety, U.S. Atomic Energy Commission, WASH 1192, 1971.

7. Kincaid, Caleb, Bureau of Radiological Health, Department of Health, Education, and Welfare, Personal communication based on best available information, January 2, 1979.

8. LeFranc, Katherine, Mining, Enforcement and Safety Administration, Department of Interior, Personal communication of information contained in annual report, February 26, 1979.

9. Proctor, Gene, NASA, Personal communication, February 13, 1979.

10. Schwebel, A., National Bureau of Standards, Personal communication, January 4, 1979.

11. Masachio, M.B., National Institutes of Health, Personal communication, December 29, 1978.

12. Background Material for the Development of Radiation Protection Standards, Staff Report of Federal Radiation Council, May 13, 1960.

13. Klement, A.W., C.R. Miller, R.P. Minx, and B. Shlein, "Estimates of Ionizing Radiation Doses in the United States 1960-2000," U.S. Environmental Protection Agency, ORP/CSD 72-1, August 1972. The estimated number of medical and dental radiation workers in the healing arts is 320,000 in this report.

material through an AEC-State Agreement. From 1960 to 1975, 26 states adopted statutes to authorize agreements with the AEC (now NRC); 25 became Agreement States. Growth in the number of byproduct licensees of the NRC (AEC) and Agreement States is shown in Figure 2. The total number of licensees nearly doubled between 1960 and 1970.

During the same period, the states became increasingly involved in all aspects of radiation protection. Before 1957 only Hawaii had enabling legislation for radiation protection regulations. By 1960 11 states, and by 1970 46, had passed such legislation (see Table 3). This increased radiation protection activity by the states provided the impetus for creating the "Suggested State Regulations for Control of Radiation." These model regulations were first published in 1962 by the Council of State Governments, aided by the AEC and the U.S. Public Health Service (36).

"Report of State and Local Radiological Health Programs," begun in 1961 by the Public Health Service, provides an annual source of regulatory data (37-53). Table 3, based on data from the report, shows growth both in the number of sources of ionizing radiation and in the size of state programs to regulate such sources.

In 1972, EPA published estimates of U.S. population exposures from several sources, including occupational (3). Table 4 summarizes 1970 occupational exposure from that study. Medical workers accounted for over 50% of the radiation work force and received about 65% of the collective dose. The AEC category included industrial activities, government sponsored research and development, and some medical uses (radionuclides).

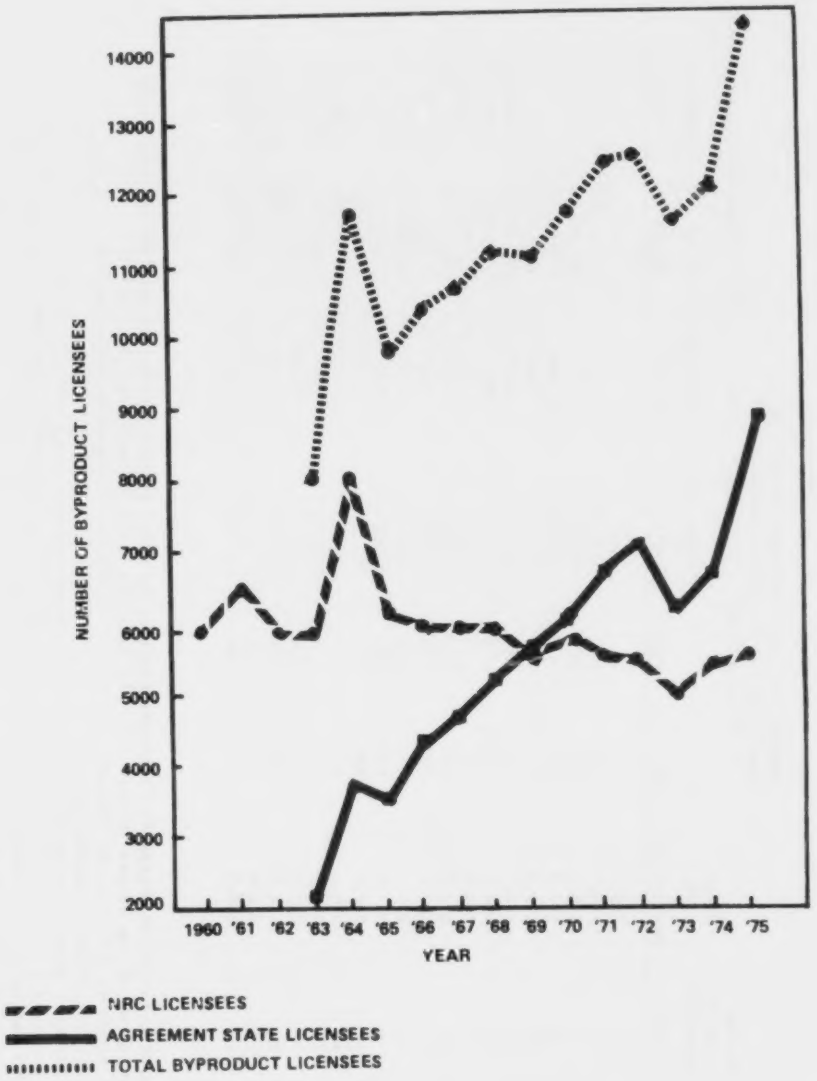


Figure 2. NRC BYPRODUCT LICENSEE GROWTH 1960-1975

Table 3. STATE RADIOLOGICAL HEALTH PROGRAMS

Fiscal Year	Number of States With Enabling Legislation[a]	Number of of NRC Agreement States	United States Population[b]	Number and Total Man-Equivalent Radiological Health Personnel of State and Local Agencies: Full	Part	Total Man-Equivalent[c]	Number of State Regulated Ionizing Radiation Devices[c]: Medical X Ray	Dental X Ray	Industrial X Ray	Particle Accelerators
1960	11	0	180.7	---	---	---	---	---	---	---
1961	17	0	183.7	178	168	210(53)	---	---	---	---
1962	21	4	186.5	177	291	237(53)	---	22550(18)	---	---
1963	31	6	189.2	244	367	312(53)	113000[d]	45930(29)	---	---
1964	33	8	191.9	297	439	375(53)	123000(37)	74360(37)	--	---
1965	35	11	194.3	346	487	437(53)	113806(53)	94174(53)	9566(49)	371[e]
1966	36	15	196.6	360	433	444(53)	109643(53)	98460(53)	10169(48)	610[f]
1967	43	17	198.7	364	423	445(53)	113284(52)	100545(52)	11028(50)	302(52)
1968	45	18	200.7	368	387	439(52)	109406(52)	98557(50)	9709(50)	576(47)
1969	45	22	202.7	389	325	448(52)	106069(50)	99956(49)	11086(45)	732(50)
1970	46	22	204.9	412	310	470(53)	109718(52)	106200(52)	4638(45)[g]	639(49)
1971	46	23	207.1	429	276	486(51)	116261(53)	117161(53)	6469(45)	790(47)
1972	47	24	208.9	467	200	507(53)	116695(52)	126704(52)	6525(47)	714(48)
1973	47	24	210.4	471	149	514(53)	120381(52)	129378(52)	6558(48)	875(48)
1974	47	25	211.9	450	176	505(52)	138491(52)	142875(52)	7546(49)	963(47)
1975	47	25	213.5	487	148	523(51)	124406(50)	139607(50)	7390(49)	833(45)
1976	49	25	215.1	523	116	566(48)	117118(48)	139133(48)	5970(45)	661(45)
1977	49	25	216.9	564	118	597(51)	128217(48)	144570(50)	6682(31)	1113(45)
1978	50	25	218.5	558	109	594(48)	116400(48)	145642(48)	5722(31)[g]	983(47)

[a] West Virginia & Wyoming have radiation protection programs functioning under General Public Health Laws of the State.
[b] Projections of the Population of the United States: 1977 to 2050, Series P-25, No. 704, July 1977.
[c] The number of States (including D.C., Virgin Islands (to 1974) & Puerto Rico) reporting data, or for which estimates are made, are given in parenthesis.
[d] Health agencies estimated that there were between 100,000 and 125,000 medical x-ray units in 1963.
[e] State health agencies reported a total of 371 particle accelerators while information from manufacturers indicated a total of 700 particle accelerators in use at end of FY 1965.
[f] Information provided principally by manufacturers.
[g] Reporting provided in terms of number of facilities instead of number of units, beginning with 1970.

Table 3. STATE RADIOLOGICAL HEALTH PROGRAMS

Fiscal Year	Number of States With Enabling Legislation[a]	Number of of NRC Agreement States	United States Population[b]	Number and Total Man-Equivalent Radiological Health Personnel of State and Local Agencies: Full	Part	Total Man-Equivalent[c]	Number of State Regulated Ionizing Radiation Devices[c]: Medical X Ray	Dental X Ray	Industrial X Ray	Particle Accelerators
1960	11	0	180.7	---	---	---	---	---	---	---
1961	17	0	183.7	178	168	210(53)	---	---	---	---
1962	21	4	186.5	177	291	237(53)	---	22550(18)	---	---
1963	31	6	189.2	244	367	312(53)	113000[d]	45930(29)	---	---
1964	33	8	191.9	297	439	375(53)	123000(37)	74360(37)	--	---
1965	35	11	194.3	346	487	437(53)	113806(53)	94174(53)	9566(49)	371[e]
1966	36	15	196.6	360	433	444(53)	109643(53)	98460(53)	10169(48)	610[f]
1967	43	17	198.7	364	423	445(53)	113284(52)	100545(52)	11028(50)	302(52)
1968	45	18	200.7	368	387	439(52)	109406(52)	98557(50)	9709(50)	576(47)
1969	45	22	202.7	389	325	448(52)	106069(50)	99956(49)	11086(45)	732(50)
1970	46	22	204.9	412	310	470(53)	109718(52)	106200(52)	4638(45)[g]	639(49)
1971	46	23	207.1	429	276	486(51)	116261(53)	117161(53)	6469(45)	790(47)
1972	47	24	208.9	467	200	507(53)	116695(52)	126704(52)	6525(47)	714(48)
1973	47	24	210.4	471	149	514(53)	120381(52)	129378(52)	6558(48)	875(48)
1974	47	25	211.9	450	176	505(52)	138491(52)	142875(52)	7546(49)	963(47)
1975	47	25	213.5	487	148	523(51)	124406(50)	139607(50)	7390(49)	833(45)
1976	49	25	215.1	523	116	566(48)	117118(48)	139133(48)	5970(45)	661(45)
1977	49	25	216.9	564	118	597(51)	128217(48)	144570(50)	6682(31)	1113(45)
1978	50	25	218.5	558	109	594(48)	116400(48)	145642(48)	5722(31)[g]	983(47)

[a] West Virgina & Wyoming have radiation protection programs functioning under General Public Health Laws of the State.

[b] Projections of the Population of the United States: 1977 to 2050, Series P-25, No. 704, July 1977.

[c] The number of States (including D.C., Virgin Islands (to 1974) & Puerto Rico) reporting data, or for which estimates are made, are given in parenthesis.

[d] Health agencies estimated that there were between 100,000 and 125,000 medical x-ray units in 1963.

[e] State health agencies reported a total of 371 particle accelerators while information from manufacturers indicated a total of 700 particle accelerators in use at end of FY 1965.

[f] Information provided principally by manufacturers.

[g] Reporting provided in terms of number of facilities instead of number of units, beginning with 1970.

Table 4. OCCUPATIONAL EXPOSURE SUMMARY FOR 1970*

Category	Number of Persons	Collective Dose (person-rems)	Mean Whole-Body Dose per Person (millirem)
AEC			
Contractors	102,918	20,361	198
Reporting Licensees			
AEC	62,090	13,365	215
Agreement State	24,519	6,715	274
Non-reporting Licensees			
AEC	93,000	5,022	54
Agreement State	3,000	822	274
Military			
Army	7,445	744	100
Air Force	17,591	1,555	88
Navy	55,051	10,879	198
PHS	508	65	129
Other Federal	2,000	258	129
Medical			
Radium	37,925	20,480	540
Non-Federal			
Medical x-ray	194,451	62,253	320
Dental x-ray	171,226	21,403	125
TOTAL	771,814	163,922	210

*Source: Estimates of Ionizing Radiation Doses in the United States 1960-2000, USEPA, Office of Radiation Programs, Criteria and Standards Division, Table IV-4, Page 148.

These accounted for 37% of the work force and 28% of the collective dose. The remaining 10% of the work force and 8% of the collective dose were mostly in the armed services and the public health service. Overall, it was estimated that 770,000 persons received an average dose of 210 mrem.

As was true a decade earlier, little monitoring data for medical and dental radiation workers, except those for which Federal agencies kept records, were available. Average annual doses of 320 mrem for non-Federal medical x-ray workers and 125 mrem for non-Federal dental x-ray workers were estimated from limited data from an occupational exposure survey in Illinois and two film-badge surveys in Wisconsin (3). Since these doses were much higher than the 90 mrem and 77 mrem reported for U.S. Air Force medical and dental personnel, the Illinois and Wisconsin data were possibly atypical. If so, the 1970 occupational dose for medicine workers was overstated. On the other hand, medical use of radiation sources in a military service may result in significantly less exposure per individual because of the existence of well-established radiation protection programs.

We conclude that the 1970 summary, while improved over the limited 1960 summary, provides exposure estimates of considerable uncertainty.

III. FACTORS IN OCCUPATIONAL EXPOSURE IN 1975

A. Types of Radiation Exposure and Personnel Dosimeters

Radiation exposures can be grouped into internal, extremity, and whole body. Internal exposure occurs when radioactive material is breathed, ingested, or absorbed into the body. Such material often concentrates in specific organs or tissues. Internal exposures are monitored infrequently. They are omitted from this report because the data are insufficient.

Extremity exposures are exposures of the hands or feet, usually from an external radiation source. These exposures typically occur when the extremities are close to radioactive sources while the torso and head are shielded by a barrier or protected by distance. This report later notes some general findings about extremity exposures based on small samples, but we cannot make projections for the national work force.

Most occupational radiation exposures are to the whole body, from x-ray, gamma ray, or neutron sources. Unless otherwise noted, subsequent discussions refer to whole-body exposure.

The two major types of personnel dosimeters used to monitor radiation are thermoluminescent dosimeters (TLD's) and film badges. The TLD "chips" are small, reusable, and readily processed. Film badges are also small, and provide a permanent record, but are not as readily processed.

B. Regulatory Authorities

No single agency regulates the exposure of workers in the United States. This resposibility is carried out by five Federal regulatory agencies with jurisdiction over exposure of workers or sources of radiation exposure in private industry, several Federal agencies who regulate exposure of their own (or their contractors') employees, and various agencies of the fifty States (see Figure 3). Some of these State agencies regulate exposure of workers under agreements with one or more of the Federal regulatory agencies, and some regulate independently. This section briefly describes the major regulatory authorities and their exposure monitoring and reporting requirements as they existed in 1975. Table 5 lists the primary authorities and identifies major legislative mandates, applicable sources of radiation, and exposure regulations.

1. Federal Authorities

The Atomic Energy Act of 1954, as amended, defines three types of radioactive material: 1) source material (uranium or thorium ore); 2) special nuclear material (enriched plutonium or uranium); and 3) byproduct material (radionuclides left over after the use of special nuclear material). The Energy Reorganization Act of 1974 transferred regulatory authority for these materials from AEC to NRC.

Only NRC licenses users of significant quantities of special nuclear material. About half the states have agreements with the NRC that give them limited authority to license users of source or byproduct materials.

AUTHORITIES FOR RADIATION PROTECTION OF WORKERS

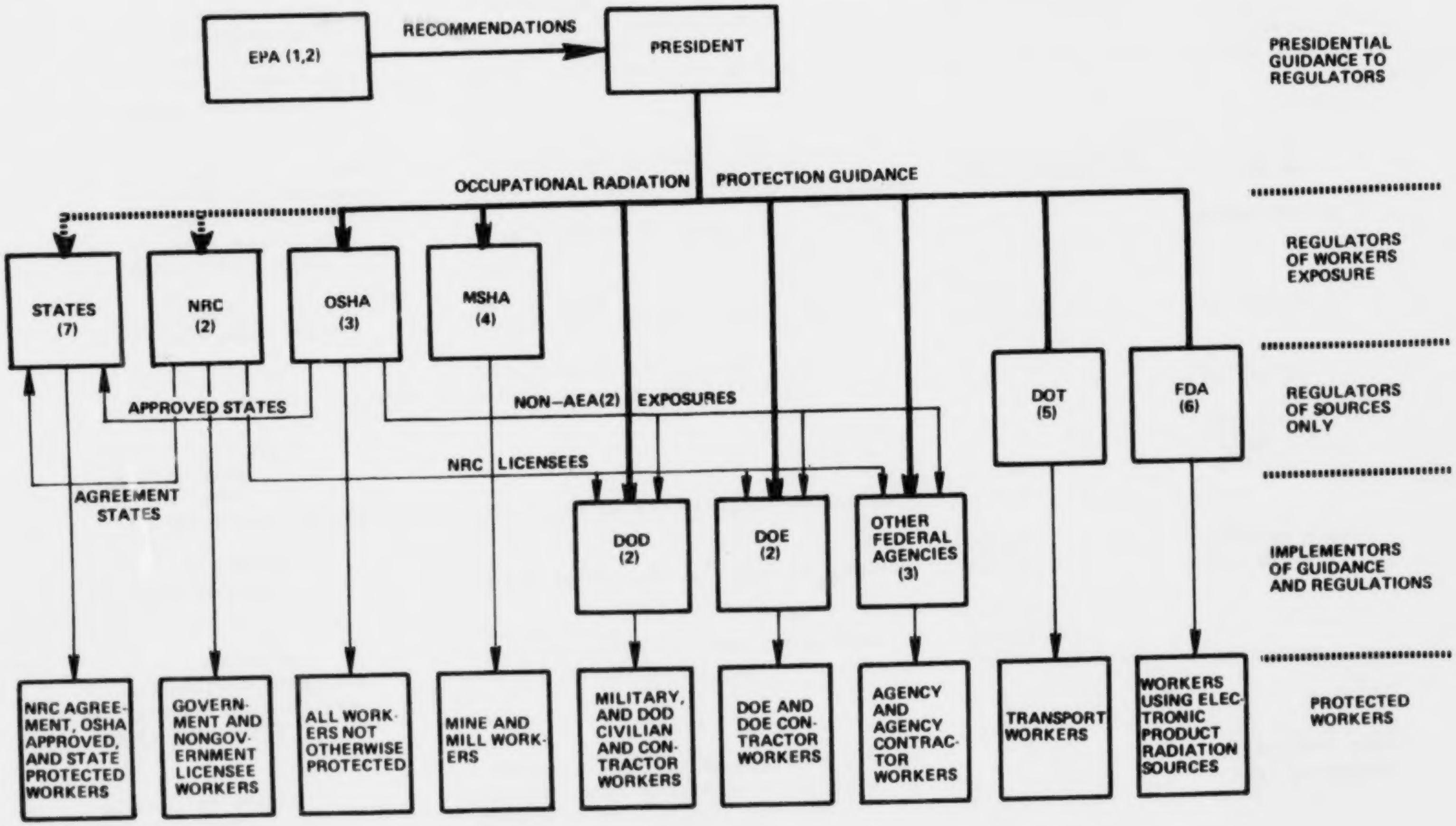

EPA (1,2)
RECOMMENDATIONS
PRESIDENT
PRESIDENTIAL GUIDANCE TO REGULATORS
OCCUPATIONAL RADIATION
PROTECTION GUIDANCE
REGULATORS OF WORKERS EXPOSURE
STATES (7)
NRC (2)
OSHA (3)
MSHA (4)
APPROVED STATES
NON–AEA(2)
EXPOSURES
DOT (5)
FDA (6)
REGULATORS OF SOURCES ONLY
NRC
LICENSEES
AGREEMENT STATES
DOD (2)
DOE (2)
OTHER FEDERAL AGENCIES (3)
IMPLEMENTORS OF GUIDANCE AND REGULATIONS
NRC AGREEMENT, OSHA APPROVED, AND STATE PROTECTED WORKERS
GOVERNMENT AND NONGOVERNMENT LICENSEE WORKERS
ALL WORKERS NOT OTHERWISE PROTECTED
MINE AND MILL WORKERS
MILITARY, AND DOD CIVILIAN AND CONTRACTOR WORKERS
DOE AND DOE CONTRACTOR WORKERS
AGENCY AND AGENCY CONTRACTOR WORKERS
TRANSPORT WORKERS
WORKERS USING ELECTRONIC PRODUCT RADIATION SOURCES
PROTECTED WORKERS

Figure 3. Occupational radiation protection guidance is binding on all major regulatory agencies except NRC and the States, in which case it is advisory. Heavy lines refer to Federal Radiation Protection Guidance; light lines indicate regulations. The authorities cited in parentheses are (1) Executive Order 10831; (2) Atomic Energy Act of 1954, as amended; (3) Occupational Health and Safety Act of 1970; (4) Federal Mine Safety and Health Act of 1977; (5) Department of Transportation Act of 1966; (6) Radiation Control for Health and Safety Act of 1968; (7) State enabling legislation and State laws.

Table 5. MAJOR REGULATORY AUTHORITIES FOR 1975 OCCUPATIONAL EXPOSURES

	General Legislative Authority	Source of Radiation	Occupational Exposure Regulations
I FEDERAL GUIDANCE			
Environmental Protection Agency	Executive Order 10831, through Reorganization Plan No. 3 of 1970 Atomic Energy Act of 1954, as amended	All	None (Fed. Radiation Protection Guid.)
II DIRECT REGULATORS			
A. Federal Authorities			
1) Nuclear Regulatory Commission	Atomic Energy Act of 1954, as amended, through Energy Reorganization Act of 1974	Source, Special (non-exempt) Byproduct	10 CFR 20
2) Department of Energy	Atomic Energy Act of 1954, as amended	Special (exempt)	DOE Manual Chapter 0524
3) Department of Defense	Atomic Energy Act of 1954, as amended	Special (exempt)	
a. Army			AR 40-14
b. Navy			NAVMED P-5055
c. Air Force			AFR 161-8
4) Department of Interior (MESA)	Federal Metal & Non-Metallic Mine Safety Act of 1966	NORM[a]	30 CFR 57
5) Department of Labor (OSHA)	Occupational Safety & Health Act Act of 1970	Electronic NARM[b]	29 CFR 19
B. State Authorities			
1) State Radiation Control Programs	Enabling State Legislation		SSRCR Part D
2) State NRC Agreement	Atomic Energy Act of 1954, as amended,	Source, Byproduct	10 CFR 20
3) State OSHA Agreement	Occupational Safety & Health Act of 1970	Electronic, NARM[b]	29 CFR 19
III INDIRECT REGULATORS			
1) Health, Education, and Welfare[c] (BRH)	Radiation Control for Health and Safety Act of 1968	Electronic	21 CFR Chapter I, Subchapter J
2) Department of Transportation	Department of Transportation Act of 1966	Source, Special Byproduct, NARM[b]	49 CFR 174-177

---

[a] Naturally Occuring Radioactive Materials
[b] Natural and Accelerator Produced Radioactive Materials
[c] Now Department of Health and Human Services

Users in the remaining states are licensed by NRC. All NRC licensees are governed by occupational exposure regulations contained in 10 CFR (Code of Federal Regulations) Part 20. NRC Agreement States must have compatible regulations. Thus, these states effectively implement 10 CFR 20 regulations.

Some special nuclear material operations need no license. The 1974 Energy Reorganization Act transferred regulatory authority of the AEC's research laboratories and other facilities to the ERDA, later the Department of Energy (DOE). Contractors who operate ERDA/DOE laboratories and facilities are exempt from NRC requirements when they use special nuclear materials to develop weapons or reactors for military vehicles or vessels. In these cases, ERDA/DOE Manual Chapter 0524 governs occupational exposures.

The Department of Defense (DOD) is also exempt from NRC licensing requirements when it uses special nuclear material for weapons or propulsion. Each service has internal regulations for occupational exposure: AR 40-14 (Army); NAVMED P-5055 (Navy); and AFR 161-8 (Air Force).

The Federal Metal and Non-Metallic Mine Safety Act of 1966 assigned the Department of Interior (DOI) regulatory authority over occupational exposure in underground mines. DOI's jurisdiction included gamma-ray exposures in uranium mines and radon exposures in all underground mines. The Federal Mine Safety and Health Act of 1977 superceded the 1975 Act, transferring the authority to the Department of Labor (DOL). The applicable occupational exposure regulations, now in 30 CFR 57, did not change.

The Occupational Safety and Health Act of 1970 established broad authority for the regulation of occupational exposure by the Occupational Safety and Health Administration (OSHA). It applies to all occupational exposures except 1) those regulated by the two acts mentioned above, and 2) those in facilities operated by states or counties in non-OSHA approved states. Federal agencies, although not subject to OSHA inspections or fines, must establish programs that conform to OSHA regulations. OSHA approves "State Plans" that allow state authorities to regulate occupational exposure. An OSHA-approved state must enforce regulations at least as rigorous as OSHA's. OSHA's occupational exposure regulations are specified in 29 CFR 1910.96.

2. State Authorities

Many state radiation control programs operate under NRC agreements and OSHA-approved state plans. Some state and Federal programs overlap. In general, Federal standards prevail unless the state's are more protective.

Many states use the Suggested State Regulations for Control of Radiation (SSRCR). These are prepared by the Conference of Radiation Control Program Directors with support from the Department of Health and Human Services (HHS), NRC, and EPA. Part D contains standards for protection against radiation and is equivalent to 10 CFR 20. NRC Agreement States effectively adopt Part D of the SSRCR.

3. Indirect Regulatory Authorities

Three Federal agencies have no direct authority for regulating exposure of workers, but indirectly affect occupational exposure.

The Secretary of HHS has authority under the Radiation Control for Health and Safety Act of 1968 to regulate the manufacture of electronic radiation-generating devices to assure their safe performance. The Bureau of Radiological Health, which administers the Act, issued regulations in 21 CFR Chapter I, Subchapter J that, among other things, limit leakage radiation from electronic source components and assemblies.

The Department of Transportation (DOT) indirectly regulates occupational exposures through its packaging, storage, and carriage regulations for radioactive materials. DOT has authority under the Department of Transportation Act of 1966 to regulate, except for postal shipments, the interstate transport of all radioactive materials, including source, special, and byproduct materials. DOT regulations are at 49 CFR 174-177.

The U.S. Postal Service indirectly affects occupational exposures through limitations on type and quantity of radioactive material shipped in the U.S. Mail. Postal shipments are covered by U.S. Postal Service Regulations, Part 124.3, U.S. Postal Service Publication #6, December 1975.

Most Federal regulations concerning occupational exposure to ionizing radiation are consistent with Federal guidance. The current guidance limits the whole-body dose accumulated over a lifetime, in rem, to 5 times the number of years beyond age 18 and to 3 rem in 13 weeks. This is equivalent to an average annual exposure of 5 rem. OSHA regulations are consistent with these limits on maximum exposures but, unlike other regulations, they do not require that doses be kept "as low as practical" within these limits. Although consistant with Federal guidance, DOT and U.S. Postal Service regulations are designed to keep the maximum annual exposure below 500 mrem, for most situations, because the general public, as well as workers, can be exposed.

C. Monitoring and Reporting Requirements

Radiation protection regulations generally include conditions for personnel monitoring. Such conditions are typically equivalent to 10 CFR 20.202, which requires monitoring of an individual who "receives, or is likely to receive" a whole-body dose in any calendar quarter of more than 312.5 mrem.

Monitoring is optional for workers likely to receive a lower dose. Therefore, actual practice varies widely. At some facilities all persons are monitored, even though exposure of most workers may be very small or zero. At others no one is monitored, though many workers may be receiving appreciable fractions of the 312.5 mrem per quarter dose. Under such conditions, any estimate of the total number of radiation workers derived by counting monitored workers is uncertain. We believe that the number of monitored persons generally sets a lower limit for the number of radiation workers. All monitored persons are therefore counted as part of the radiation work force. There are, however, difficulties in extrapolating monitoring data for some segments of the work force. These are discussed later.

Besides uncertainties in monitoring practices for workers receiving less then 312.5 mem, there are various reporting requirements for summaries of workers receiving any radiation. Even when monitoring is required and done, the dose data are not necessarily reported or available for analysis of occupational exposures. OSHA has no requirements for reporting radiation exposures unless excessive. OSHA's authority covers about three-quarters of the radiation work force.

NRC requires (10 CFR 20.407) nuclear power reactor; industrial radiographer; fuel processor, fabricator, and reprocessor; and commercial processor and distributor of specified quantities of byproduct materials licensees--but no others--to submit an annual report of personnel monitoring information. The report includes a statistical summary of individuals for whom personnel monitoring was either required or provided during the calendar year. NRC summarizes these data in an annual occupational radiation exposure report (25-28). In 1978, NRC ordered a special two-year study during which all licensees were to provide summaries of occupational exposure information (43 FR 44827, Sept. 29, 1978).

DOE requires its contractors to provide annual summary reports of all monitoring data. This information is published in an annual report of radiation exposures (23,24).

All of DOD maintains personnel monitoring and record systems. Not all exposure data in DOD systems are summarized or published on an annual basis. The Naval Security Systems Command, which monitors radiation exposures to Navy and civilian personnel in the Naval Nuclear Propulsion program, now summarizes exposure information annually (35).

IV. DATA SOURCES AND SUMMARY METHODS

We could not develop a single, simple, reliable system for compiling a comprehensive summary of annual occupational exposure in the United States. Instead, we had to pursue several methods. This chapter describes the specific sources of 1975 data and the methods we used to analyze them.

A. Data Sources

The two major sources of occupational exposure data for this report were Federal government agencies and commercial dosimetry service records. Federal agency exposure data provided a nearly complete sample for one-quarter of the work force. Commercial data covered about one-fifth of the work force.

1. Government

We assumed that monitored workers represent potentially exposed workers for occupations or facilities for which Federal agencies have compiled exposure data. Appendix D gives Federal exposure summaries for 1975.

DOD had the largest number of monitored workers in government for 1975. Within DOD, the Navy had the largest number. DOE had the second largest monitored work force, and NRC reporting licensees the third largest. Data from other Federal agencies included relatively few workers. Table 6 summarizes available 1975 exposure data from Federal sources.

Air Force data provided exposure summaries for 20 occupational categories (see Appendix D). These data provided the greatest occupational detail for any group of government or government contractor employees.

NRC summarizes whole-body exposure for four licensee categories in its annual Report on Occupational Radiation Exposure. DOE (ERDA) also publishes annual radiation exposure summaries for 10 occupational categories. Both reports give the distribution of workers by dose range according to the reporting format of 10 CFR 20.

The records of the Mine Safety Health Administration (MSHA) report exposures of miners to radon decay products in units of working level months. Since these data are not directly comparable to whole-body doses in rem units, we did not use them in this report.

2. Commercial

We early recognized that data from government agencies alone would be insufficient for some occupational categories to allow estimating the number of workers and their exposures. Federal summaries simply do not include data for electronic product sources in medical, educational, and industrial occupations in the public sector. We therefore obtained a sample of occupational exposure data from a commercial dosimetry firm. These data consisted of individual records rather than summary tables.

Table 6. SUMMARY OF 1975 OCCUPATIONAL EXPOSURE DATA FROM FEDERAL AGENCIES

Federal Agency	Personnel Dosimetry Processor	Occupational Category Detail	Number of Workers		Mean Annual Whole-Body Dose* (millirem)	
			Monitored	Exposed	Monitored	Exposed
Dept. of Defense						
Navy	In-house	Fleet, Shipyard, Non-nuclear Navy	60,400	43,700	160	220
Army	In-house	None	16,000	6,700	30	60
Air Force	In-house	Occupation	16,100	5,400	10	40
SUBTOTAL			92,500	55,800	110	180
DOE (ERDA-1975)						
Reactor Research	In-house	Facility Type	6,727	5,286	420	530
Uranium Enrichment	In-house	Facility Type	7,471	5,664	50	70
Weapon F & T	In-house	Facility Type	19,425	7,846	70	180
General Research	In-house	Facility Type	33,769	14,339	90	210
Accelerator	In-house	Facility Type	7,384	2,382	150	450
Other	In-house	Facility Type	11,479	9,139	290	370
DOE Offices	In-house	Facility Type	2,170	459	20	100
SUBTOTAL			88,425	45,115	140	270
NRC						
Power Reactors	Commercial	Facility Type	54,763	28,034	390	760
Fuel Fabrication and Reprocessing	Commercial	Facility Type	11,405	5,495	270	570
Industrial Radiography	Commercial	Facility Type	9,178	4,693	300	590
Manufacturing and Distribution	Commercial	Facility Type	3,367	1,859	350	640
SUBTOTAL			78,713	40,081	360	710
BRH	Commercial	None	2,392	1,481	60	90
NIH	Commercial	None	2,183	179	10	170
NASA	Commercial	None	1,410	274	20	120
NBS	(Army)	None	393	190	50	110
(MSHA)	In-house	None	3,344)**			
TOTAL			266,018	143,120		

* Mean value of whole-body dose rounded to nearest 10 mrem

** Environmental monitoring for radon and its decay products - number of workers not included in TOTAL.

Some records included the age and sex of workers. A smaller number of records contained extremity dose information.

We do not believe the commercial data to be as representative or reliable as government data. Government data are generally representative because monitoring practices and regulatory requirements provide relatively complete records for an identified occupational group. Government data are generally reliable because anomalous or spurious exposure records are normally investigated and verified.

Commercial service data, on the other hand, have recognized weaknesses:

- Unless the service maintains the permanent exposure record of a customer's employees, spurious or anomalous records are likely to remain uncorrected.
- Raw commercial data may include records based on a customer's evaluation of environmental exposures or dosimeter performance when no worker is actually exposed.
- In particular, commercial data may be questionably representative for occupational categories with low exposures and no regulatory reporting requirements.

Available resources did not permit us to evaluate these weaknesses, so we used commercial data only if government data were unavailable.

B. Methods for Summarizing Data

Two methods were used to project those portions of the radiation work force not contained in government summaries. In general, these methods involved the computation of average doses and number of workers per radiation facility, licensee, or registrant from commercial data. Then based upon the total number of facilities, licensees, or registrants obtained from other studies, we projected the number of workers and their collective dose for identified occupational categories.

List Method

Except for users of certain exempt radionuclides or radionuclide quantities, users of radionuclide sources are licensed by the NRC or NRC-Agreement States. Users of electronic radiation sources register their facility with state radiation control programs. We requested nine state programs and NRC to list all radiation users according to type of radiation source and type of industry and occupation. We then had a commercial dosimetry service compile exposure data by industry and occupation for all of its clients appearing on the state and NRC lists. This produced 75,000 exposure records, collated into various occupational categories. (See Appendix A for comprehensive details of List Method.)

Code Method

The commercial dosimetry service began to group and code its clients into over 50 occupational or facility categories after the List Method approach had begun. This permitted a second way to analyze commercial data. The commercial service then created a statistical summary of its 200,000-record data base by client code, as well as by groups that corresponded to some categories of the List Method. However, no distinction by radiation source was possible with the Code Method. (Appendix B provides complete details.)

National Summary Method

Neither the Code nor List Method generated an accurate summary for all occupational categories. We therefore revised each method to conform to other relevant data, such as personnel resource statistics. (These revisions and their results are described in Appendices A and B.) The revised versions of the List and Code Methods also disagreed in some occupational categories. We therefore made a "best estimate" summary, using the results we believed to be most accurate for each category. The MEDICINE category estimate is based on the Code Method; the INDUSTRY estimate on the List Method. We based the NUCLEAR FUEL CYCLE category and most of the GOVERNMENT category on Federal agency data. In the MISCELLANEOUS category, we included educational projections from a separate EPA analysis; we based transportation projections on the Final Environmental Statement on the Transport of Radioactive Materials by Air and other Modes, NUREG-0170 (see Appendix C).

C. Radiation Work Force and Exposure Data

Figure 4 illustrates the relative size and composition of work force segments and of exposure data used in this report. The outlined areas are scaled to the relative number of workers in that segment of the work force.

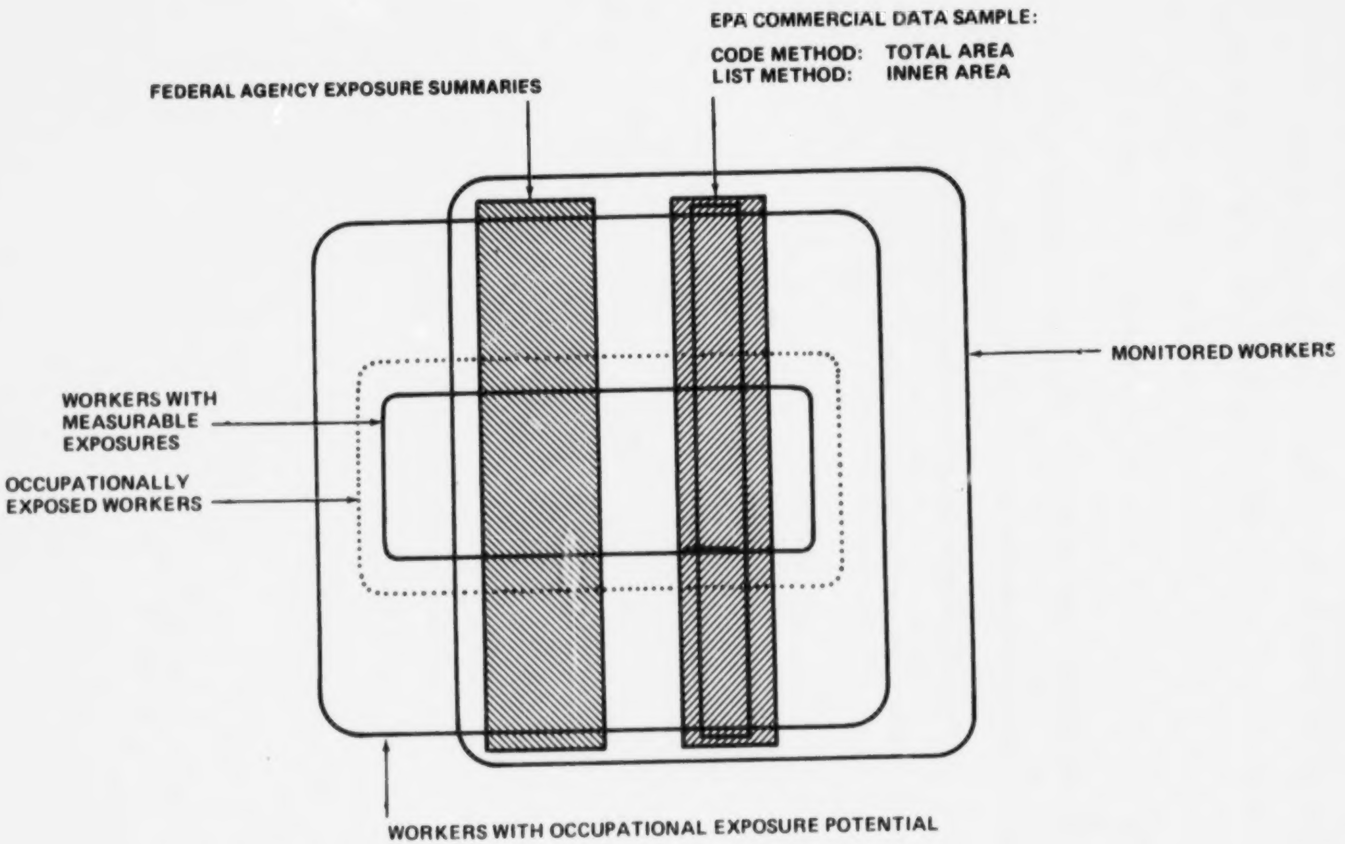

EPA COMMERCIAL DATA SAMPLE:
CODE METHOD: TOTAL AREA
LIST METHOD: INNER AREA
FEDERAL AGENCY EXPOSURE SUMMARIES
MONITORED WORKERS
WORKERS WITH MEASURABLE EXPOSURES
OCCUPATIONALLY EXPOSED WORKERS
WORKERS WITH OCCUPATIONAL EXPOSURE POTENTIAL

Figure 4. SCHEMATIC DIAGRAM OF WORK FORCE SEGMENTS AND EXPOSURE DATA SOURCES USED IN THIS REPORT

Within the set of all ("Total") workers with occupational exposure potential is the set of all actually exposed workers; within this is the set of measurably exposed ("Exposed") workers. The border of the occupationally exposed worker set is dotted because the relative size of this group is uncertain. The set of monitored workers includes some with no exposure potential, yet it omits some who are measurably exposed.

We considered the Federal and commercial data to be separate subsets (shaded areas) of the monitored worker group. In the List Method, we used about 40% of the total available data from the commercial firm. In the Code Method, we used almost the entire set of commercial data.

V. NATIONAL OCCUPATIONAL EXPOSURE SUMMARY FOR 1975

A. Occupational Categories

We have used five major categories: MEDICINE, INDUSTRY, NUCLEAR FUEL CYCLE, GOVERNMENT, and MISCELLANEOUS. Some occupational categories in this report lack detailed subcategories. This is because scanty detail sometimes forced us to present worker exposure by facility type rather than by specific occupation. The scope of category detail thus ranges from specific professional groups to entire industrial sectors. For example, we can identify Dentistry, Podiatry and Chiropractic as separate medical subcategories. On the other hand, information in the industrial sector limited us to dividing this large group into three subcategories. Table 7 describes the categories and their subcategories used in the national summary.

B. Results

1. Composition of the Radiation Work Force.

Table 8 presents our "best estimate" summary of the number of workers for the national radiation work force in 1975 and their average and collective doses.

There were about 1.1 million persons ("total") in the radiation work force. About 370,000 persons ("exposed") received a measurable dose. The average doses for these populations were 120 and 350 mrem, respectively.

Table 7. OCCUPATIONAL CATEGORIES & SUBCATEGORIES USED IN THIS REPORT

Category/Subcategory	Description	Summary Method
MEDICINE	Non-Federal occupations involving medical diagnostic or therapeutic use of naturally occuring, byproduct, accelerator produced radioactive materials, and/or electronic sources of ionizing radiation.	Revised Code (See Appendix B)
Hospital/Clinic	Physicians, nurses, technologists, radiopharmacists, and medical physicists at large medical facilities and university hospitals (military and Veterans Administration hospital/clinics are included in GOVERNMENT category).	Revised Code
Private Practice	Physicians, nurses, technologists, etc. in private, group, or clinic practices smaller than Hospital/Clinic facilities and generally owned privately.	Revised Code
Dental	Dentists, dental hygienists and dental assistants.	Revised Code
Podiatry	Podiatrists and assistants	Revised Code
Chiropractic	Chiropractors and assistants.	Revised Code
Veterinary	Veterinarians and assistants.	Revised Code
INDUSTRY	Occupations that entail exposure from radionuclide and electronic sources in industry and private enterprise other than the practice of medical sciences.	Revised List (See Appendix A)
Manufacturing and Distrib. of Radiation Sources	Occupations associated with development, delivery, or installation of radiopharmaceutical, brachytherapy, and electronic sources of radiation.	Revised List
Industrial Radiography	Nuclear Regulatory Commission (NRC) and NRC Agreement State Licensees classified as radiographers.	Revised List
Industrial Users of Radiation Sources	Users of radionuclide and electronic sources for a wide variety of purposes, including non-destructive testing, well-logging, thickness gauging, etc.	Revised List
NUCLEAR FUEL CYCLE	Includes all fuel cycle occupational activities except uranium mining.	Principally NRC & DOE Annual Reports
Nuclear Power Reactors	Maintenance, operation, and inspection personnel and transient workers.	NRC
Nuclear Fuel Fabrication & Reprocessing	Fabrication, Reprocessing and related occupations.	NRC
Uranium Enrichment	Occupations involved in uranium enrichment at Department of Energy (DOE) contractor facilities.	DOE

Table 7. (Continued)

Category/Subcategory	Description	Summary Method
Nuclear Waste Disposal	Low Level Waste disposal - government contractor disposal operation not included - some waste transportation personnel included.	Revised List
Uranium Mills	Uranium Mill NRC licensees not required to report exposures.	Revised List
GOVERNMENT	Includes occupational exposures at Veterans Administration (VA) and Military hospitals and Civil Defense facilities.	Federal Agencies
Department of Defense	Includes exposures to medical personnel in all three services as well as Nuclear Navy (Ships and Shipyards) and special nuclear material exposure.	Army, Navy, and Air Force
Government (Federal)	Veterans Administration (VA), National Institutes of Health (NIH), National Aeronautics and Space Administration (NASA), National Bureau of Standards (NBS), etc.	VA, NIH, NASA, NBS, etc.
Department of Energy	Researchers and other personnel at DOE and DOE contractor facilities.	DOE
MISCELLANEOUS	Occupational groups involving Education and Transportation.	Code & Resource Data (Appendix C)
Education	Faculty, staff, & students who work with radiation sources. Colleges & Universities included in "4-year"; Technical schools and Community colleges included in "2-year" groups.	Code & Resource Data (Appendix C)
Transportation	Personnel involved in transportation of radioactive materials by airlines, railroads, common freight carriers, etc.	NRC & Resource Data (Appendix C)
ADDITIONAL GROUPS		
Education - Students	Students exposed during courses.	Code & Resource Data (Appendix C)
Transportation - Incidental	Flight attendants on airlines carrying radioactive materials.	NRC & Resource Data (Appendix C)

Table 8. NATIONAL OCCUPATIONAL EXPOSURE SUMMARY FOR 1975[a]

Occupational Subgroup	Number of Workers Total[b]	Number of Workers Exposed[c]	Mean Whole-Body Dose (millirem) Total[b]	Mean Whole-Body Dose (millirem) Exposed[c]	Collective Dose (person-rems)
MEDICINE					
Hospital/Clinic	100,000	55,100	220	400	22,000
Private Practice	137,800	53,300	160	410	21,700
Dental	265,700	41,400	20	140	5,800
Podiatry	10,100	2,100	10	30	100
Chiropractic	14,600	3,700	30	110	400
Veterinary	18,100	6,200	80	230	1,400
Entire Subgroup	546,300	161,800	90	320	51,400
INDUSTRY[d]					
Industrial Radiography Licensees	19,800	9,700	290	580	5,700
Other Industrial Users					
Licensees	114,100	18,800	100	610	11,400
Registrants	55,900	16,000	110	370	5,900
Source Manuf. & Distr.					
Licensees	7,000	3,900	350	630	2,500
Registrants	4,000	800	40	200	200
Entire Subgroup	200,800	49,200	130	520	25,600
NUCLEAR FUEL CYCLE					
Power Reactors	54,763	28,034	390	760	21,400
Fuel Fabrication and Reprocessing	11,405	5,495	270	560	3,100
Uranium Enrichment	7,471	5,664	50	70	400
Nuclear Waste Disposal	300	100	10	920	100
Uranium Mills	300	100	20	50	-
Entire Subgroup	74,200	39,400	340	630	24,900

Table 8. (Continued)

Occupational Subgroup	Number of Workers		Mean Whole-Body Dose (millirem)		Collective Dose (person-rems)
	Total[b]	Exposed[c]	Total[b]	Exposed[c]	
GOVERNMENT					
Dept. of Energy	80,954	39,451	150	300	11,800
Dept. of Defense	92,500	55,800	110	180	10,100
Other Federal Govt.	13,400	4,400	90	280	1,300
Entire Subgroup	186,800	99,700	120	230	23,100
MISCELLANEOUS					
Education (Faculty):					
2-year Institutions	7,000	2,300	60[e]	170	400
4-year Institutions	14,800	4,900	80[e]	230	1,100
Transportation	77,000	11,800	30	200	2,300
Entire Subgroup	98,800	19,000	40	200	3,800
ALL WORKERS	1,106,900	369,100	120	350	128,800
ADDITIONAL GROUPS[f]					
Transportation (Flight Attendants; radionuclides)	30,000	10,000	-	10	100
Education (Students):					
2-year Institutions	35,000	11,700	60[e]	170	2,000
4-year Institutions	54,800	18,300	80[e]	230	4,200
All Additional Groups	119,800	40,000	50	150	6,100

[a] Extrapolated numbers of workers are rounded to the nearest 100, mean doses to the nearest 10 mrem, and collective doses to the nearest 100 person-rem.

[b] All monitored and unmonitored workers with potential occupational exposure.

[c] Workers who received a measurable dose in any monitoring period during the year.

[d] "Licensee" means NRC and NRC agreement state licensees for use of radionuclides. Doses from electronic (e.g., x-ray) sources are also included. "Registrant" means state registrants, who have electronic sources only.

[e] These estimated doses are based on small samples that may not be representative.

[f] Persons who are only incidentally exposed or not normally considered workers; the estimates listed are very uncertain.

The "total" workers in the MEDICINE, INDUSTRY, NUCLEAR FUEL CYCLE, GOVERNMENT, and MISCELLANEOUS groups received average doses of 90, 130, 340, 120, and 40 mrem respectively. The collective dose was about 129,000 person-rems. Two additional groups, flight attendants and students, totalled 120,000 persons. We omitted them from the total radiation work force because their status, numbers, and exposures were largely uncertain.

We based many of our worker extrapolations on the number of monitored persons per facility as reported by commercial data. We expect that because of cost considerations, lack of reporting requirements, and other factors, these data generally omit workers who receive low radiation doses. The exposed but unmonitored worker population could be substantial in some cases, particularly for low-exposure occupations. We consider populations projected from such data to be least estimates. On the other hand, we believe that the commercial data tend to represent larger-than-average facilities (clients). When these data are used to set persons-per-facility ratios, this would bias population estimates upward. We think that these factors counteract each other to some extent.

a. Average doses considerations.

The average doses, above, for "total" workers are based on all potentially exposed workers, including those who received zero or no measurable dose. These average doses are inappropriate when considering only those workers actually exposed. We therefore present below a brief summary for "exposed" workers.

The NUCLEAR FUEL CYCLE category had the largest average dose, at 630 mrem. The INDUSTRY category had the next largest average dose, at 520 mrem.

The MEDICINE, GOVERNMENT, and MISCELLANEOUS categories had considerably lower average doses: 320, 230, and 200 mrem respectively. The "exposed" work force can be divided into two major segments. One consists of about 90,000 workers (NUCLEAR FUEL CYCLE and INDUSTRY) who averaged about 570 mrem/year. A second, much larger, group numbers about 280,000 workers (MEDICINE, GOVERNMENT, and MISCELLANEOUS) who averaged about 280 mrem/year. The latter segment received 60% of the collective dose.

b. Distribution of work force and collective dose.

Figures 5 and 6 illustrate some main features of the summary data. Figure 5 shows each major category's percentage of the total extrapolated work force. The MEDICINE group was the largest, comprising almost half the work force. The INDUSTRY (18%) category was second, followed by GOVERNMENT (17%) and MISCELLANEOUS (9%). The NUCLEAR FUEL CYCLE (7%) had the smallest share of the radiation work force. The shaded areas represent that portion of the category estimated to have received a measurable dose. The NUCLEAR FUEL CYCLE and GOVERNMENT categories had by far the highest percentage of workers with measurable dose.

Figure 6 shows the distribution of collective dose by major occupational category. The MEDICINE (40%) category had about double the nearly equal INDUSTRY (20%), NUCLEAR FUEL CYCLE (19%), and GOVERNMENT (18%) shares of the collective dose.

c. Dose range distributions.

Figure 7 shows the projected distribution of the national work force by dose range according to our data sample of 475,000 workers. Two-thirds of

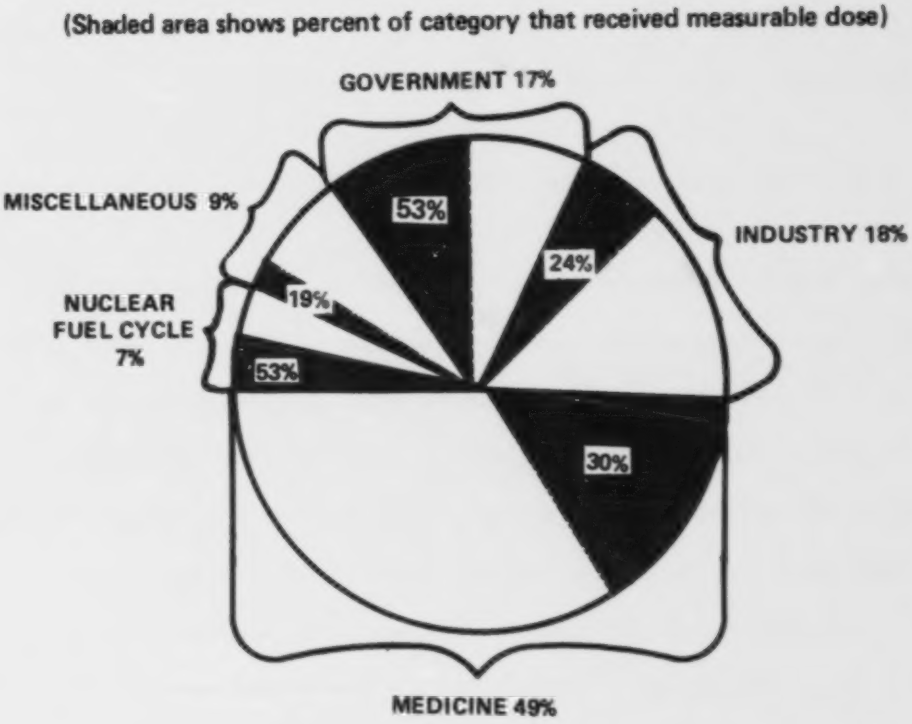


Figure 5. DISTRIBUTION OF RADIATION WORK FORCE BY OCCUPATION

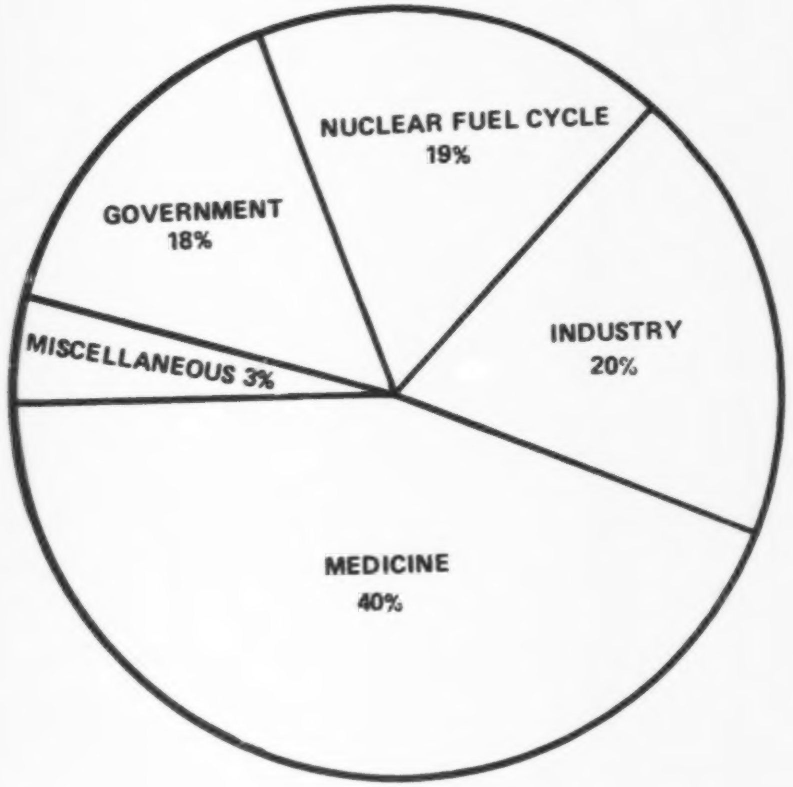


Figure 6. DISTRIBUTION OF COLLECTIVE DOSE BY OCCUPATION

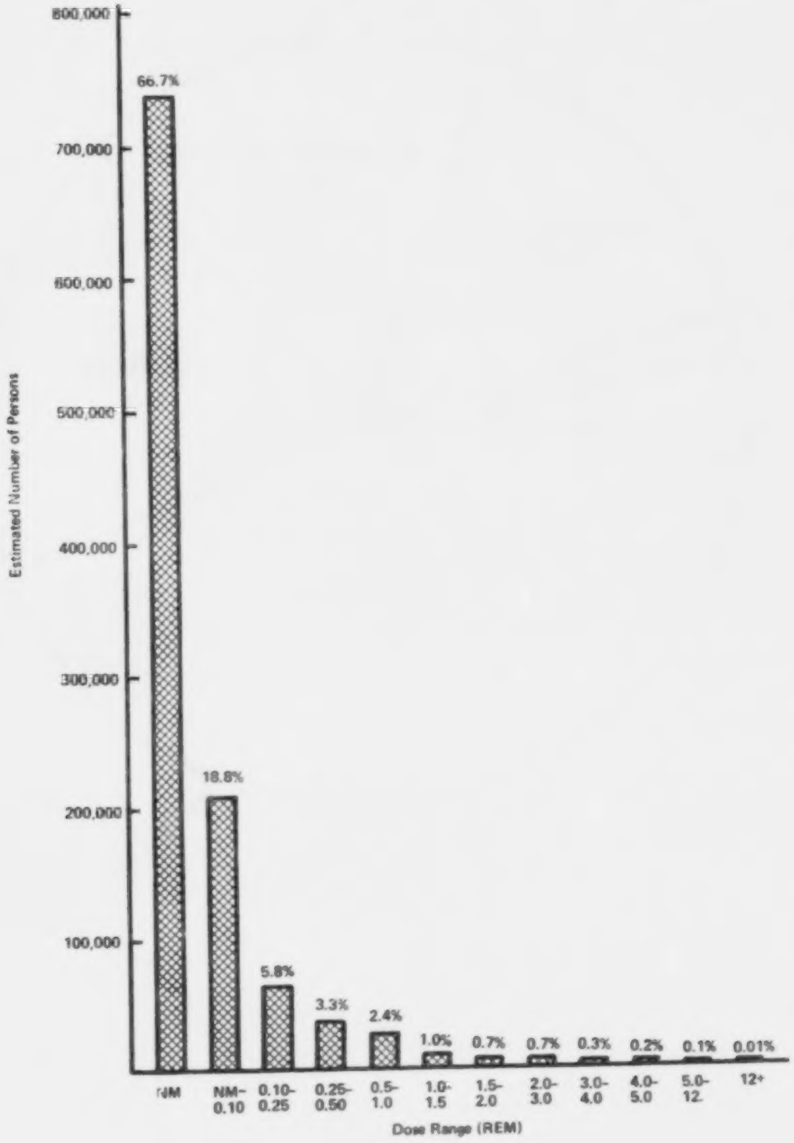


Figure 7. DISTRIBUTION OF WHOLE-BODY DOSE FOR THE RADIATION WORK FORCE

the workers did not receive a measurable dose. About 85% of the workers received less than 100 mrem and about 95% less than 500 mrem. About 0.15% of the workers received more than 5 rem.

Table 9 shows the projected distribution of doses by occupational category. We found that a greater percentage of exposures exceed 5 rems for those categories represented by commercial data than in the government and closely regulated sectors, where data came directly from government summaries. We do not know whether this difference is real or an artifact caused by misrepresentations in the commercial data or government summaries. The last column in Table 9 gives the actual or estimated percentage of workers in categories for which we had exposure data.

2. Extrapolations by Age and Sex for Major Occupational Categories

Some of the commercial data had age and sex information. We do not know how representive it was, but we had no other age and sex data. The following age and sex projections assume that the 120,000 age and sex coded commercial records were representative for the five major categories of the radiation work force.

a. Potentially exposed work force.

Table 10 shows distribution of potentially exposed persons ("total"), extrapolated by age and sex for the major occupational categories. Overall, men outnumbered women 4 to 3. Women outnumbered men 5 to 3 in the MEDICINE category. The number of men and women were fairly close in the MISCELLANEOUS category, but men outnumbered women in the three other

Table 9. DISTRIBUTION OF 1975 RADIATION WORK FORCE BY DOSE RANGE AND OCCUPATION

Category	DOSE RANGE																			
	Rem																		Percent of Total Work Force	Whole-Body Records As Percent of Extrap. Population
	Less Than Meas.[a]	Meas.[b]–0.099	0.100–0.249	0.250–0.499	0.500–0.749	0.750–1.0	1.0–1.99	2.0–2.99	3.0–3.99	4.0–4.99	5.0–5.99	6.0–6.99	7.0–7.99	8.0–8.99	9.0–9.99	10.0–10.99	11.0–11.99	12+[c]		
	Percent																			
MEDICINE																				
Hospital/Clinic	45.	25.	12.	8.0	3.6	2.0	2.9	0.82	0.30	0.17	0.07	0.05	0.02	0.02	0.01	0.01	0.00	0.04	9.0	89.
Private Practice	63.	20.	7.5	4.3	1.9	0.94	1.6	0.50	0.22	0.14	0.09	0.05	0.02	0.02	0.00	0.02	0.02	0.03	13.	18.
Dental	84.	11.	2.1	0.87	0.34	0.24	0.24	0.09	0.09	0.05	0.05	0.00	0.05	0.00	0.00	0.00	0.00	0.00	24.	0.8
Chiropractic	75.	18.	3.7	2.5	0.69	0.23	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.3	2.9
Veterinary	66.	23.	5.8	2.8	1.0	0.64	0.71	0.22	0.09	0.12	0.03	0.03	0.03	0.00	0.03	0.00	0.00	0.03	1.6	17.
Category Subtotal	70.	17.	5.6	3.2	1.4	0.76	1.1	0.33	0.16	0.10	0.06	0.02	0.03	0.01	0.00	0.01	0.01	0.02	49.	22.
INDUSTRY																				
Industrial Radiography	51.	19.	8.5	6.4	3.6	2.8	5.6	1.8	0.68	0.37	0.23	0.09	0.01	0.03	0.01	0.02	0.01	0.01	1.8	58.
Other Industrial	80.	9.5	3.4	2.1	1.2	0.62	1.8	0.86	0.54	0.25	0.04	0.03	0.05	0.01	0.02	0.02	0.00	0.01	15.	9.
Manufacturing and Distribution	57.	16.	11.	4.8	1.9	2.3	2.9	1.2	0.81	0.81	0.21	0.23	0.05	0.00	0.02	0.00	0.00	0.00	1.0	50.
Category Subtotal	75.	11.	4.3	2.7	1.4	0.92	2.2	0.98	0.56	0.29	0.07	0.05	0.04	0.01	0.02	0.02	0.00	0.01	18.	16.
NUCLEAR FUEL CYCLE																				
Nuclear Power Reactors	49.	19.	7.5	5.4	3.2	2.5	7.3	3.4	1.3	0.77	0.31	0.11	0.04	0.02	0.00	0.00	0.00	0.00	4.9	100.
Fuel Fabrication and Reprocessing	52.	17.	9.7	9.0	3.8	2.1	3.3	1.3	0.68	0.35	0.26	0.09	0.08	0.12	0.13	0.00	0.00	0.00	1.0	100.
Uranium Enrichment	24.	70.	3.8	1.4	0.39	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	100.
Uranium Mills	75.	20.	5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	30.
Nuclear Waste Disposal[e]	68.	18.	9.0	5.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	8.
Category Subtotal	47.	24.	7.4	5.5	3.0	2.2	5.9	2.7	1.0	0.63	0.27	0.10	0.04	0.04	0.02	0.00	0.00	0.00	6.7	99.

Table 9. (Continued)

DOSE RANGE

Category	Less Than Meas.[a]	Meas.[b]–0.099	0.100–0.249	0.250–0.499	0.500–0.749	0.750–1.0	1.0–1.99	2.0–2.99	3.0–3.99	4.0–4.99	5.0–5.99	6.0–6.99	7.0–7.99	8.0–8.99	9.0–9.99	10.0–10.99	11.0–11.99	12[c]	Percent of Total Work Force	Whole-Body Records As Percent of Extrap. Population
	Rem																			
	Percent																			
GOVERNMENT																				
Government	67.	17.	7.9	3.6	1.6	0.62	1.3	0.28	0.17	0.10	0.05	0.03	0.00	0.05	0.00	0.00	0.00	0.00	1.2	50.
Military	40.	43.	7.5	4.0	1.9	1.1	1.9	0.89	0.28	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.4	100.
Research and Development	51.	29.	8.7	4.3	2.1	1.3	2.2	0.91	0.28	0.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.3	100.
Category Subtotal	47.	35.	8.0	4.1	1.9	1.1	2.0	0.86	0.27	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	17.	97.
MISCELLANEOUS																				
Education:																				
2-yr institution	67.	22.	5.4	3.2	0.94	0.57	0.37	0.16	0.09	0.00	0.00	0.04	0.00	0.01	0.00	0.00	0.00	0.01	0.63	6.8
4-yr institution	67.	20.	6.5	3.2	1.3	0.64	1.1	0.51	0.32	0.07	0.04	0.02	0.02	0.01	0.00	0.03	0.01	0.02	1.3	25.
Transportation	85.	8.7	4.4	1.5	0.43	0.16	0.13	0.07	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	7.0	3.9
Category Subtotal	81.	11.	4.7	1.8	0.60	0.26	0.30	0.14	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	8.9	13.
TOTAL Work Force	67.	19.	5.8	3.3	1.5	0.91	1.7	0.68	0.30	0.17	0.06	0.03	0.03	0.01	0.01	0.01	0.00	0.01	100.0	36.

---

[a] Includes annual records reporting 0 mrem/month for all 12 months.

[b] Includes annual records reporting at least 10 mrem (generally reported detectability limit) for at least one month, but less than 100 mrem in total for the year.

[c] Personnel dosimetry errors may be responsible for a considerable percentage of exposure records exceeding 12 rems.

[d] Podiatry is included in Private Practice.

[e] Extrapolated dose distribution for waste disposal is based on possibly non-representative commercial dosimetry data.

Table 10. EXTRAPOLATED DISTRIBUTION OF WORKERS BY AGE AND SEX FOR MAJOR OCCUPATIONS*

CATEGORY	AGE 18-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-65	66+	Total
	Number											
MEDICINE												
Male	6,075	36,414	45,321	44,461	26,099	20,296	11,251	10,191	5,003	3,378	973	209,462
Female	30,117	124,913	68,697	43,807	22,624	18,200	11,550	10,129	3,868	2,440	493	336,838
INDUSTRY												
Male	2,494	20,460	30,291	30,364	20,568	21,399	14,640	15,435	8,097	4,555	434	168,737
Female	1,410	6,145	5,314	4,518	2,783	3,506	2,639	3,181	1,590	868	109	32,063
NUCLEAR FUEL CYCLE												
Male	363	9,949	17,428	15,432	7,515	5,228	5,664	4,720	2,468	1,016	0	69,783
Female	688	2,063	507	543	217	145	145	109	0	0	0	4,417
GOVERNMENT												
Male	684	14,008	24,828	32,118	14,123	15,262	10,478	12,984	5,125	4,101	227	133,938
Female	1,481	12,759	11,735	7,405	5,241	3,645	3,190	5,127	1,595	684	0	52,862
MISCELLANEOUS												
Male	1,288	11,683	11,762	11,468	6,915	4,079	2,209	4,258	859	644	233	55,398
Female	4,857	15,840	8,552	4,947	2,523	2,165	1,360	2,102	617	367	72	43,402
TOTAL												
Male	10,904	92,514	129,630	133,843	75,220	66,264	44,242	47,588	21,552	13,694	1,867	637,318
Female	38,553	161,720	94,805	61,220	33,388	27,661	18,884	20,648	7,670	4,359	674	469,582

---

*The numbers of work force members for the occupational categories and age groups are expressed to the nearest unit for internal arithmetic consistency in this report. They are not significant beyond one or two figures.

categories. About 65% of the potentially exposed workers were younger than 35 years old. Females 20 to 24 years old in the MEDICINE category alone comprised about one-fourth of all women in the radiation work force.

b. Collective dose.

Table 11 shows the distribution of the collective whole-body dose by age and sex, extrapolated for the major occupational categories. Figure 8 illustrates the contribution to the total collective dose by age group for men and women. Men outnumber women in total collective dose by more than 3 to 1. Figure 9 shows collective dose distribution by age, sex and occupational category.

Men received about 19%, 19% and 16% of the total collective dose in the NUCLEAR FUEL CYCLE, INDUSTRY, and GOVERNMENT categories, respectively. Women received only about 3% of the total collective dose in these three categories combined. Men and women in the MEDICINE category each accounted for about 20% of the total. Women 20 to 24 years old in the MEDICINE category alone received nearly 8% of the total collective dose. This was the most for either sex in any age group for any activity. It primarily reflected the large number of women in this age group within MEDICINE. The MISCELLANEOUS category accounted for only 3% of the total collective dose.

c. Average whole-body dose.

Table 12, derived from Tables 10 and 11, shows the average doses for all potentially exposed workers ("total") by age group and sex for the

Table 11. EXTRAPOLATED DISTRIBUTION OF WHOLE-BODY COLLECTIVE DOSE (PERSON-REMS) BY AGE AND SEX FOR MAJOR OCCUPATIONS*

CATEGORY	AGE 18-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-65	66+	Total
	Person-rems											
MEDICINE												
Male	392	4,161	5,172	6,193	2,927	4,249	1,159	895	370	230	124	25,872
Female	1,751	10,047	5,014	3,186	1,858	1,363	1,357	598	184	145	25	25,528
INDUSTRY												
Male	525	5,334	6,357	3,938	3,597	1,966	1,337	782	450	43	1	24,330
Female	32	432	491	74	41	106	21	35	16	22	0	1,270
NUCLEAR FUEL CYCLE												
Male	172	4,913	6,807	5,067	2,738	1,688	1,253	1,275	555	149	0	24,617
Female	67	174	26	9	3	3	1	0	0	0	0	283
GOVERNMENT												
Male	333	3,711	3,473	5,144	2,123	1,852	1,276	2,173	816	336	6	21,243
Female	77	457	475	286	389	105	20	34	14	0	0	1,857
MISCELLANEOUS												
Male	159	287	701	515	197	106	97	54	5	35	0	2,156
Female	198	957	197	94	75	28	24	55	8	8	0	1,644
TOTAL												
Male	1,581	18,406	22,510	20,857	11,582	9,861	5,122	5,179	2,196	793	131	98,218
Female	2,125	12,067	6,203	3,649	2,366	1,605	1,423	722	222	175	25	30,582

---

*The numbers of person-rems for the occupational categories and age groups are expressed to the nearest unit for internal arithmetic consistency in this report. They are not significant beyond one or two figures.

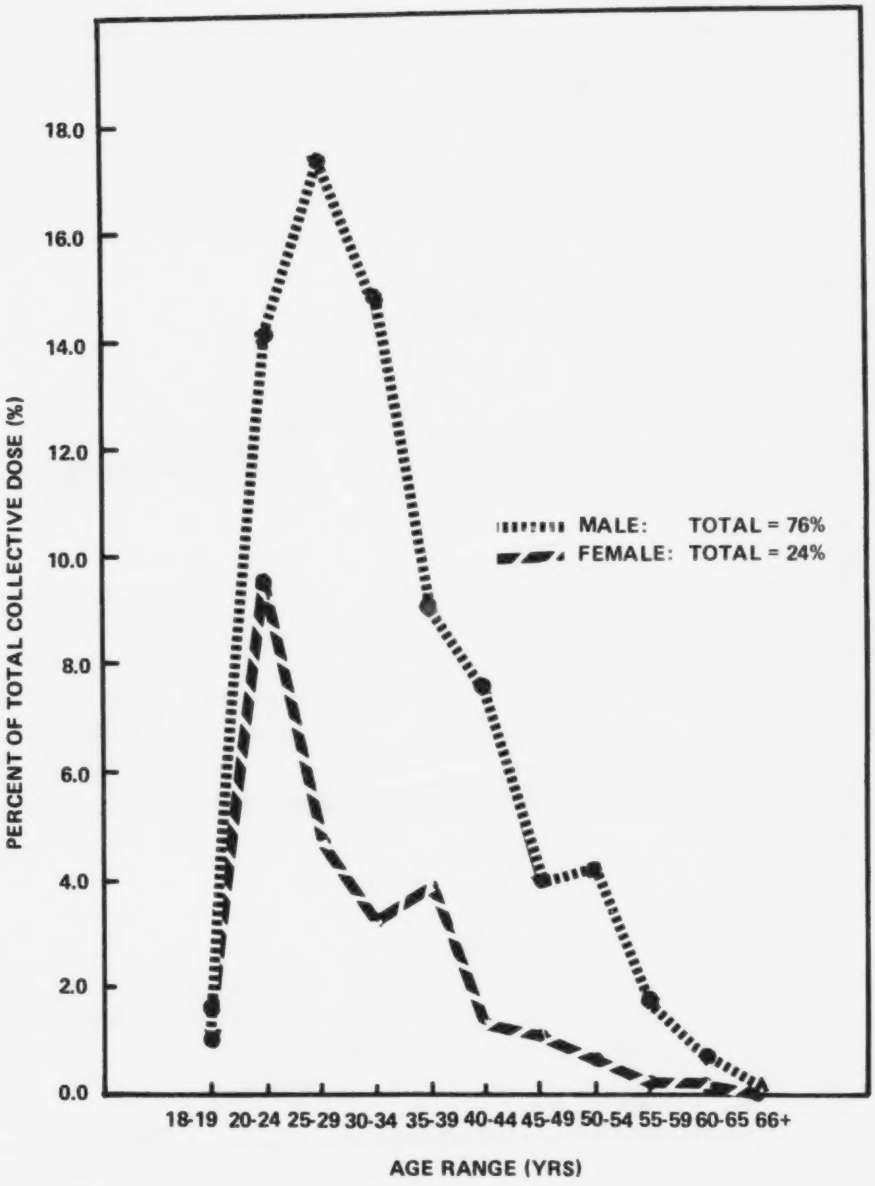


Figure 8. DISTRIBUTION OF COLLECTIVE DOSE BY AGE AND SEX

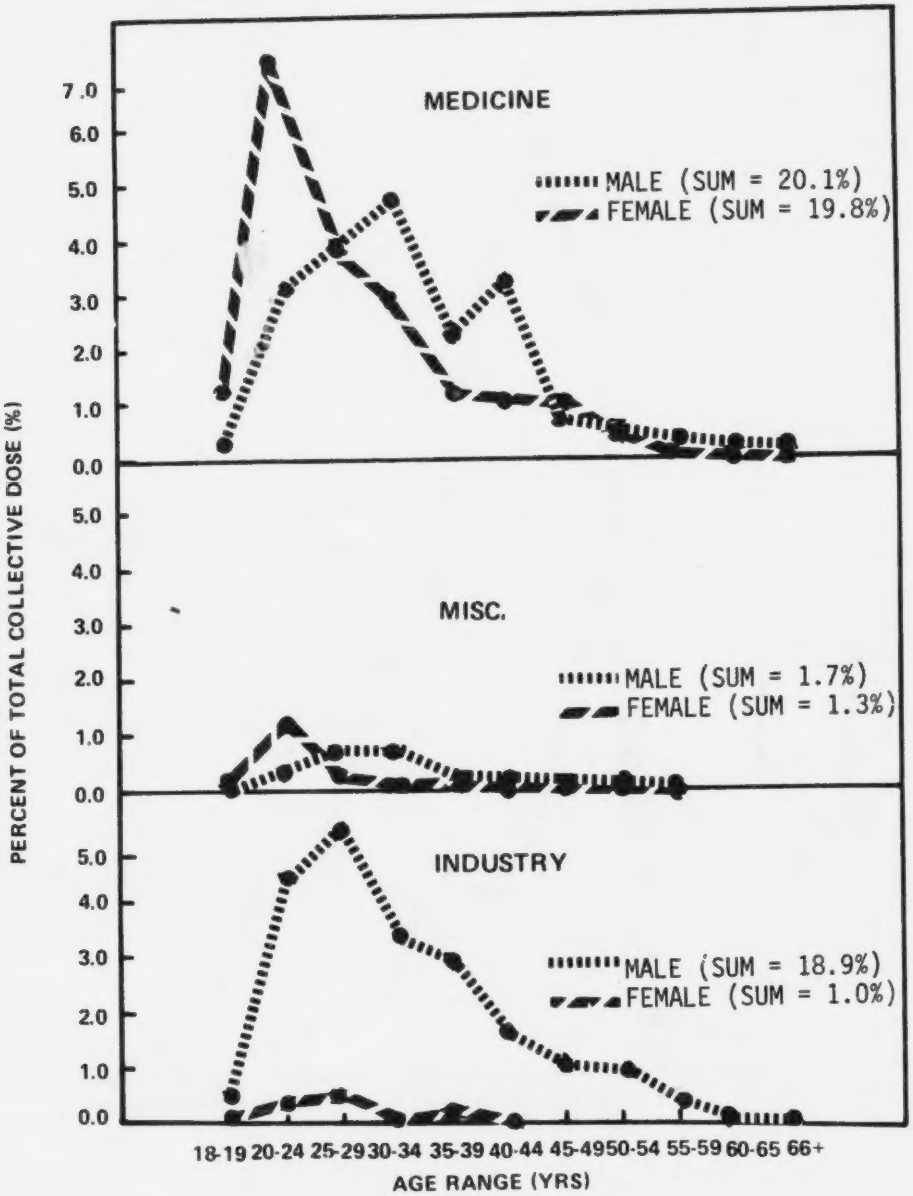


Figure 9. DISTRIBUTION OF COLLECTIVE DOSE BY OCCUPATION, AGE, AND SEX

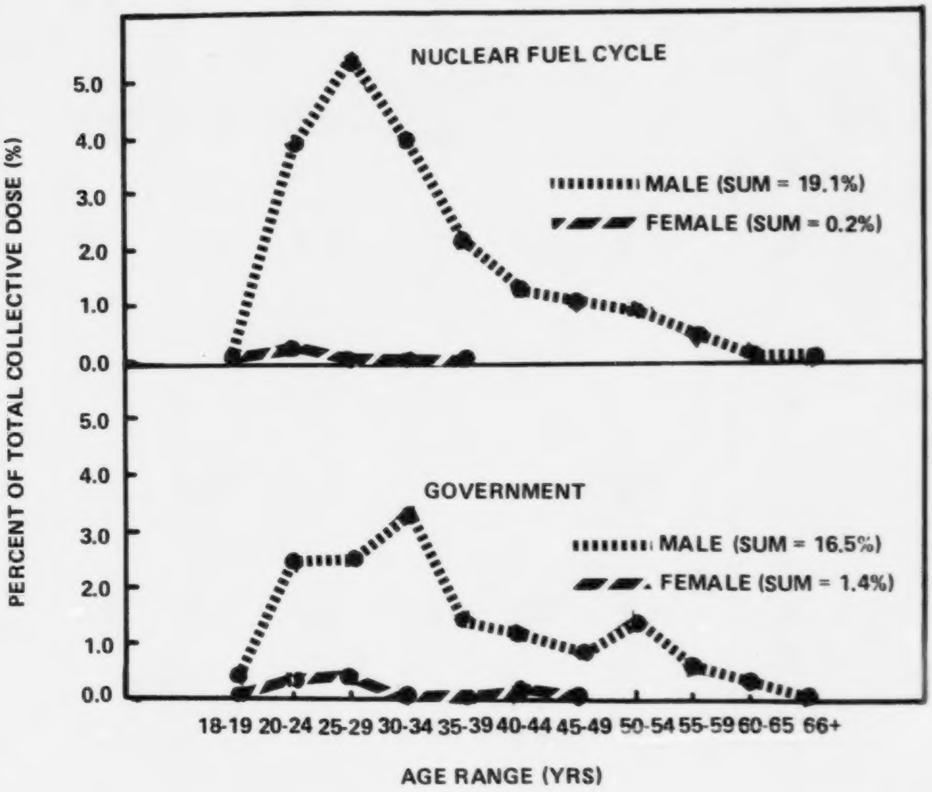


Figure 9. (Continued)

Table 12. EXTRAPOLATED DISTRIBUTION OF MEAN WHOLE-BODY DOSE (MILLIREM) BY AGE AND SEX FOR MAJOR OCCUPATIONS*

	AGE										
CATEGORY	18-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-65	66+	Total
	millirem											
MEDICINE												
Male	60	110	110	140	110	210	100	90	70	70	130	120
Female	60	80	70	70	80	70	120	60	50	60	50	80
INDUSTRY												
Male	210	260	210	130	170	90	90	50	60	10	0	140
Female	20	70	90	20	10	30	10	10	10	30	0	40
NUCLEAR FUEL CYCLE												
Male	470	490	390	330	360	320	220	270	220	150	0	350
Female	100	80	50	20	10	20	10	0	0	0	0	60
GOVERNMENT												
Male	490	260	140	160	150	120	120	170	160	80	30	160
Female	50	40	40	70	30	10	10	16	0	0	0	40
MISCELLANEOUS												
Male	120	20	60	40	30	30	40	10	10	50	0	40
Female	40	60	20	20	30	10	20	30	10	20	0	40
TOTAL												
Male	140	200	170	160	150	150	120	110	100	60	70	150
Female	60	70	70	60	70	60	80	30	30	40	40	70

---

*Values of Mean Whole-Body Dose are rounded to the nearest 10 millirem.

major occupational categories. On average, men had twice the radiation exposure of women, though in some occupations men had four to five times the exposure of women. Male workers ages 18 to 24 in the NUCLEAR FUEL CYCLE and GOVERNMENT categories had the highest average doses of all workers. Average doses generally decreased with workers' age in all categories.

3. Calculated Lifetime Doses

Neither government nor commercial exposure records furnished lifetime exposure data. We roughly estimated average lifetime doses by assuming that the average dose/age group distribution given in Table 12 represents an equilibrium, or unchanging, distribution. The average lifetime dose for potentially exposed workers then was the sum of the average annual dose from age 18 to 65. So, the average lifetime dose for potentially exposed ("total") workers from age 18-65 was about 6.7 rem for men and 2.9 rem for women. The corresponding lifetime dose estimates for measurably exposed ("exposed") workers was about 20 rems for men and 8.6 rems for women.

4. Average Doses for Established Dose Range Intervals.

Conforming to 10 CFR 20.407, certain NRC licensees submit annual reports that give the distribution of workers exposed in a series of dose ranges. Some other agencies also use this dose range scheme for annual exposure summaries. Collective dose and overall average dose can only be approximated, however. because the summaries omit actual exposure values.

One technique for estimating the collective dose from a dose range distribution of workers is to assume that the mid-point of each range approximates the average dose for workers in that range. The sum of the products of these midpoints and the corresponding number of workers in each dose range gives an estimate of the collective dose. This collective dose divided by the total number of workers, then provides an estimate of the overall average dose. Assumption of the midpoint approximation can produce large collective dose errors, however, because the distribution of persons vs. dose range is appreciably skewed toward lower doses (see Figure 7.).

Since the commercial data did include actual reported doses (to the nearest 10 mrem), we calculated true average doses for each of the 10 CFR 20.407 dose ranges and compared them with the corresponding midpoint approximations. Table 13 gives this comparison. It shows that the midpoint approximation can badly overestimate the actual average. In the dose range from 0.01 to 0.10 rem, the overestimate was 41%. Overall, we found a cumulative difference of +7.5% between the midpoint approximation and the true mean value of collective dose for workers receiving between 0.01 and 5.0 rem. The bottom of the table shows that using the midpoint approximation for the 0 - 1 rem and larger dose ranges overestimates the collective dose even more. This was common practice in early exposure summaries.

5. Contribution to Collective Dose from Doses Reported as Less Than Measurable.

Table 9 shows that 67% of the projected work force received "less-than-measurable" doses in 1975. Differences in such factors as

Table 13. COMPARISON OF TWO COLLECTIVE DOSE ESTIMATES: DOSE RANGE MIDPOINTS VS. DOSE RANGE MEANS

	MIDPOINT AND MEAN DOSES			COLLECTIVE DOSE		
Dose Range (rem)	Range Midpoint (rem)	Range Mean (rem)	Range Population (persons)	Range Midpoint (person-rems)	Range Mean (person-rems)	Midpoint Excess (%)
<0.01*	-	--	737,954	--	--	-
0.01 - 0.10	0.055	0.039	207,761	11,427	8,103	41.0
0.10 - 0.25	0.175	0.157	64,174	11,230	10,075	11.5
0.25 - 0.50	0.375	0.351	36,560	13,710	12,833	6.8
0.50 - 0.75	0.625	0.609	17,053	10,658	10,385	2.6
0.75 - 1.00	0.875	0.856	10,029	8,775	8,585	2.2
1.00 - 2.00	1.500	1.388	18,856	28,284	26,172	8.1
2.00 - 3.00	2.500	2.431	7,576	18,940	18,417	2.8
3.00 - 4.00	3.500	3.469	3,360	11,760	11,656	0.9
4.00 - 5.00	4.500	4.470	1,873	8,429	8,372	0.7
Summary for above ranges	-	--	1,105,196	123,213	114,598	7.5
BROAD SUMMARY DOSE RANGES						
0.00 - 1.0	0.500	0.045	1,073,531	536,766	48,309	1,011
0.01 - 1.0	0.505	0.148	335,577	169,466	49,665	241
0.00 - 5.0	2.500	0.101	1,105,196	2,762,990	111,625	2,375
0.01 - 5.0	2.505	0.313	367,242	919,941	114,947	700

---

*Doses below 0.01 rem are considered less than measurable.

monitoring procedures, detectability limits, and background corrections, determine which workers are placed in this dose range. The range generally includes workers whose dosimeters read something less than 10 mrem in every monitoring period (typically one month) of the year. We can examine the potential contribution to collective dose from those workers estimated to receive "less-than-measurable" doses. We will do so by assuming a log-normal distribution of workers as a function of dose (32,34).

The possible contribution to collective dose from such workers could be sizable. For example, if all such persons averaged a monthly dose of 5 mrem, this would increase the 128,800 person-rems total given in Table 8 by 44,400 person-rems (.005 rem/month x 12 months x 740,000 workers). The pronounced skew in the distribution of workers toward lower doses, however, suggests that the true collective dose contribution from the less-than-measurables is much less than 44,400 person-rems.

We fitted the Table 9 data for workers receiving more than 100 mrem with a log-normal distribution. Extrapolating this distribution down to 1 mrem, we estimated a possible contribution to collective dose from the less-than-measurables. About 86% of the work force received less than 100 mrem and 30% received less than 1 mrem. For the 56% of workers between 1 and 100 mrem, we interpolated an average annual dose for 11 approximately equal fractions of 5%. We then estimated collective dose from this portion of the work force by summing the products of interpolated average dose and corresponding work force number.

Table 14 presents some details. The collective dose derived from the extrapolation for the 10-100 mrem dose range is about 10,000 person-rems, compared to an observed 8,103 person-rems. This suggests that in this range actual data account for about 80% of the estimated collective dose. For the 1-10 mrem range, we only derive an additional 1800 person-rems --much less than the midpoint approximation of 44,400 person-rems suggested above.

Table 14. DOSE CONTRIBUTION FROM DOSES REPORTED AS LESS-THAN-MEASURABLE

Cumulative Percent of Work Force	Dose Range (millirem)	Average Annual Dose (millirem)	Number of Workers	Collective Dose (person-rems)
86-100	100+	(See Tables 9,10 & 14)	154,920	120,697
80-86	50-100	75.0	66,410	4,982
75-80	30-50	40.0	55,350	2,214
70-75	20-30	25.0	55,350	1,384
65-70	14-20	17.0	55,350	941
60-65	9.0-14	11.5	55,350	637
55-60	6.5-9.0	7.75	55,350	429
50-55	4.5-6.5	5.50	55,350	304
45-50	3.0-4.5	3.75	55,350	208
40-45	2.0-3.0	2.50	55,350	138
35-40	1.5-2.0	1.75	55,350	97
30-35	1.0-1.5	1.25	55,350	69
0-30	0.0-1.0	0.00	332,070	0
			1,106,900	132,100

Including log-normal extrapolation for exposures below 100 mrem, we calculated a total collective dose of about 132,100 person-rems. This effectively added only 3,300 to the previous total of 128,800 person-rems, an increase of less than 3%. This small contribution does not significantly affect either the collective dose or the average dose for the work force.

One last point concerning "less-than-measurable" doses: each individual's reported exposure is often determined by subtracting some average background value obtained from control dosimeters. Negative results are reported as zero. This creates an upward bias in reported values that may compensate for the assumption that "less-than-measurable" doses are zero. If so, however, this bias in the 10-100 mrem range would have led us to predict that the observed collective dose (8,103 person-rems) should be larger than the extrapolated collective dose (approximately 10,000 person-rems). That this did not happen could mean, alternatively, that the log-normal extrapolation is not appropriate. Nevertheless, we conclude from the above considerations that the potential errors from neglecting "less-than-measurable" doses are small.

6. Extremity Exposures

One of our initial objectives was to estimate extremity exposures for the U.S. radiation work force. We obtained some extremity exposure data from the commercial dosimetry firm, but could not determine how representative they were. (Appendix E gives the distribution.) Though we could not devise suitably extrapolated national totals from these data, we found that approximately half of the records showed no measureable exposure while less than 0.1% of the records gave exposures greater than 30 rem.

VI. SOURCES OF ERROR AND UNCERTAINTY

A. Measurement Error

Besides uncertainties that our assumptions and extrapolations introduced, the dosimetry records themselves may contain errors that equal or exceed those that any subsequent analyses cause. Monitoring data actually represent doses to dosimeters; the worker assigned the dosimeter might receive the same-- and might not. There are several reasons for discrepancies; for example, the worker is exposed but the dose is inaccurately measured, or the worker is not exposed but a faulty dosimeter yields a measurable dose. In addition, accurate dose measurement is particularly difficult in mixed fields of gamma, x-ray, and neutron radiation.

Some dosimetry data from commercial processors are likely less reliable than government data as previously discussed in Section V.A.2. The AEC reached a similar conclusion after contracting with several film-badge companies for statistical data on licensees for the years 1966-1971 (54-58). The inconsistencies between these statistical studies and the AEC's own licensee data were serious.

A recent NRC-sponsored study of personnel dosimeter performance indicates that many processors would have difficulty passing draft performance standards proposed by the Health Physics Standards Committee and tentatively adopted by the American National Standards Institute (ANSI) as N13.11 (59,60). In two tests, 22% and 14% of dosimeters were in error by more than 50%. Despite poor performances by individual dosimeters, the same study showed that the mean value for a large number of dosimeters probably characterizes average and collective doses for groups of workers adequately.

The NRC study showed that the average bias $\bar{P}$ (where $P=(D-D_o)/D_o$, D=reported dose and D_o=delivered dose) of reported doses (where all D_o values were less than 10,000 mrem) was: (a) 0.28 high for low energy x rays (15-30 kev), (b) 0.17 high for medium energy x rays (30-300 kev), (c) 0.03 high for cobalt-60 gamma rays (1.2-1.3 Mev), (d) 0.23 high for Strontium 90 betas, (e) 0.21 low for californium-252 neutrons (thermal to several Mev), (f) 0.81 high for photon mixture of Cobalt-60 gamma rays and medium energy x rays, (g) 0.15 high for photon and beta mixtures, and (h) 0.10 low for photon and neutron mixtures. The corresponding standard deviation for the above average biases (number of dosimeters in each category in parenthesis) was, respectively: (a) 1.6 (2650), (b) 3.6 (4772), (c) 5.3 (3321), (d) 0.53 (1544), (e) 0.48 (1188), (f) 19. (4396), (g) 0.47 (3096), and (h) 0.68 (1136). If we assume that all 23,960 dosimeters (including 1857 accident doses in the 10-800 rad range) of this study are representative of dosimetry used for the U.S. work force, the average bias was 0.24 high. The corresponding standard deviation was 8.7.

We did not further examine dosimetry performance in this study. We assumed that all dosimetry data with reported values of less than 12 rem represent actual exposures. There was some difficulty with the commercial data because a considerable number of reported doses greatly exceeded 12 rem. Appendix A discusses the steps we took to minimize this problem.

B. Dosimeter Misuse

Personnel dosimeters may be exposed without exposing the assigned wearer, and vice-versa. The dosimeter readings would overstate the actual dose received in the first case and understate it in the second. Such occurences are generally unintentional. Occasionally, however, a monitored individual may deliberately misuse the dosimeter. If an employer pays more for work performed in a radiation field, a worker might shield his dosimeter to work longer for more pay. Or, if the work is unpleasant--for example, performed in extreme heat and humidity--the worker might place his dosimeter near a radiation source to leave the job sooner. Both such abuses have occurred. We cannot say how frequently they occurred in 1975.

C. Conclusion

We did not try to examine and measure all errors linked with personnel dosimetry and work force extrapolations. The NRC study of personnel dosimetry performance leads us to conclude that information on the number of workers potentially exposed may be better than information on their actual exposure. The overall accuracy of the participating dosimetry services was disappointing, especially since the radiation sources for each of the eight radiation categories were known (59,60). We do not know to what extent the choice of personnel dosimeters is tailored to the various kinds of radiation to which workers are exposed. In addition, we know that dosimeter readouts are adjusted differently for background corrections.

All of these considerations lead us to conclude that mean and collective dose values for most categories of occupational workers, as well as for the entire national work force, are probably known to within no better than 30%.

REFERENCES

1. "Radiation Protection Guidance for Federal Agencies," Federal Radiation Council--Approved by President Eisenhower (25 F.R. 4402), May 18, 1960.

2. "Background Material for the Development of Radiation Protection Standards," Staff Report of Federal Radiation Council, May 13, 1960.

3. Klement, A.W., C.R. Miller, R.P. Minx, and B. Shleien, "Estimates of Ionizing Radiation Doses in the United States 1960-2000," United States Environmental Protection Agency, ORP/CSD 72-1, August 1972.

4. Hayes, D.F., "A Summary of Accidents and Incidents Involving Radiation in Atomic Energy Activities; June 1945 - December 1955," U.S. Atomic Energy Commission, TID-5360, August 1956.

5. "A Summary of Industrial Accidents in U.S. AEC Facilities, January - December 1956," Supplement 1 to TID-5360, U.S. Atomic Energy Commission, August 1957.

6. "A Summary of Industrial Accidents in U.S. AEC Facilities, January - December 1956," Supplement 1 (Revised) to TID-5360, U.S. Atomic Energy Commission, August 1958.

7. "A Summary of Industrial Accidents in U.S. AEC Facilities, 1947-1958," Supplement 2 to TID-5360, U.S. Atomic Energy Commission, August 1959.

8. "A Summary of Industrial Accidents in U.S. AEC Facilities, 1959-1960," Supplement 3 to TID-5360, U.S. Atomic Energy Commission, August 1961.

9. "A Summary of Industrial Accidents in U.S. AEC Facilities, 1961-1962," Supplement 4 to TID-5360, U.S. Atomic Energy Commission, August 1963.

10. "A Summary of Industrial Accidents in U.S. AEC Facilities, 1962-1964," Supplement 5 to TID-5360, U.S. Atomic Energy Commission, August 1965.

11. "A Summary of Industrial Accidents in U.S. AEC Facilities, 1965-1966," Supplement 5 to TID-5360, U.S. Atomic Energy Commission, August 1967.

12. "Registry of Information on Personnel Overexposures to Ionizing Radiation," Second Report, January 1972 - December 1973, U.S. Atomic Energy Commission.

13. "Registry of Information on Personnel Overexposures to Ionizing Radiation," Third Report, January 1972 - May 1974, U.S. Atomic Energy Commission.

14. Eason, C.F., "First Year's Experience in the Reporting and Recording of Occupational Radiation Exposure Information in the Central Repository," U.S. Atomic Energy Commission, WASH-1350-R1, April 1970.

15. Eason, C.F., "A Report of the Second Year's Experience in the Reporting and Recording of Occupational Radiation Exposure Information in the Commissions Central Repository," U.S. Atomic Energy Commission, WASH-1350-R2, December 1970.

16. "The Centralization of Occupational Radiation Exposure Information, A Report by the Assistant for Workman's Compensation and Radiation Records of the U.S. Atomic Energy Commission's Experience 1970," U.S. Atomic Energy Commission, WASH-1350-R3, 1971.

17. "Fourth Annual Report of the Operation of the U.S. Atomic Energy Commission's Central Repository of Individual Radiation Exposure Information," U.S. Atomic Energy Commission, WASH-1350-R4, September 1972.

18. "Fifth Annual Report of the Operation of the U.S. Atomic Energy Commission's Centralized Ionizing Radiation Exposure Records and Reports System," U.S. Atomic Energy Commission, WASH-1350-R5, July 1973.

19. "Sixth Annual Report of the Operation of the U.S. Atomic Energy Commission's Centralized Ionizing Radiation Exposure Records and Reports System," U.S. Atomic Energy Commission, WASH-1350-R6, September 1974.

20. "A Compilation of Occupational Radiation Exposures from Light Water Cooled Nuclear Power Plants 1969-1973," USAEC, WASH-1311, May 1974.

21. "Seventh Annual Report of Radiation Exposures for AEC and AEC Contractor Employee - 1974," Energy Research and Development Administration, ERDA-76/119.

22. "Eighth Annual Report of Radiation Exposures for ERDA and ERDA Contractor Employees - 1975," Energy Research and Development Administration, ERDA 77-29.

23. "Ninth Annual Report of Radiation Exposures for DOE and DOE Contractor Employees - 1976," U.S. Department of Energy, DOE/EV-0011/9, April 1978.

24. "Tenth Annual Report of Radiation Exposures for DOE and DOE Contractor Employees - 1977," U.S. Department of Energy, DOE/EV-0066/10, March 1980.

25. Brooks, B.G., "Seventh Annual Occupational Radiation Exposure Report, 1974," United States Nuclear Regulatory Commission, NUREG-75/108, November 1975.

26. Brooks, B.G., "Eighth Annual Occupational Radiation Exposure Report 1975," United States Nuclear Regulatory Commission, NUREG-0119, October 1976.

27. Brooks, B.G., "Ninth Annual Occupational Radiation Exposure Report, 1976," United States Nuclear Regulatory Commission, NUREG-0322, October 1977.

28. Brooks, B.G., "Tenth Annual Occupational Radiation Exposure Report, 1977," United States Nuclear Regulatory Commission, NUREG-0463, October 1978.

29. Murphy, T.D. and C.S. Hinson, "Occupational Radiation Exposure at Light Water Cooled Power Reactors, 1969-1974," United States Nuclear Regulatory Commission, NUREG-75/032, June 1975.

30. Murphy, T.D., N.J. Dayem, J.S. Bland, and W.J. Pasciak, "Occupational Radiation Exposure at Light Water Cooled Power Reactors, 1969-1975," NUREG-0109, August 1976.

31. Johnson, L.A., "Occupational Radiation Exposure at Light Water Cooled Power Reactors, 1976," United States Nuclear Regulatory Commission, NUREG-0323, March 1978.

32. Cool, W.S., "Occupational Radiation Exposure at NRC-Licensed Facilities," U.S. Nuclear Regulatory Commission, NUREG-0419, March 1978.

33. "Operational Accidents and Radiation Exposure Experience within the United States Atomic Energy Commission, 1943-1970," U.S. Atomic Energy Commission, WASH 1192, Fall 1971.

34. Wald, N., A.A. Spritzer, and A. Brodsky, "A Pilot Study of Occupational Exposure to Ionizing Radiation," Graduate School of Public Health, University of Pittsburgh Report Number 8 (Final Report and Summary), December 27, 1960 - December 27, 1964.

35. Miles, M.E. and W.R. Kindley, "Occupational Radiation Exposure from U.S. Naval Nuclear Propulsion Plant and Their Support Facilities," Department of the Navy, Report NT-79-2, February 1979.

36. "Suggested State Regulations for Control of Radiation," Conference of Radiation Control Program Directors, Inc., U.S. Nuclear Regulatory Commission, U.S. Environmental Protection Agency and U.S. Department of Health, Education, and Welfare, October 1978.

37. "Expenditures and Basic Needs for Radiological Health Programs in State and Territorial Public Health Agencies - First Status Report," U.S. Department of Health, Education, and Welfare, Public Health Service, Division of Radiological Health, March 1961.

38. "Expenditures and Basic Needs for Radiological Health Programs in State and Territorial Public Health Agencies - Second Status Report," U.S. Department of Health, Education, and Welfare, Public Health Service, Division of Radiological Health, April 1962.

39. "Status Report of State and Local Radiological Health Programs - Fiscal Years 1962 and 1963," U.S. Department of Health, Education and Welfare, SAB DOC 460-2-64, July 1964.

40. "Report of State and Local Radiological Health Programs - Fiscal Year 1964," U.S. Department of Health, Education, and Welfare, SAB DOC 460-1-65, May 1965.

41. "Report of State and Local Radiological Health Programs - Fiscal Year 1965," U.S. Department of Health, Education, and Welfare, SAB DOC 460-3-66, June 1966.

42. "Report of State and Local Radiological Health Programs - Fiscal Year 1966," U.S. Department of Health, Education, and Welfare, CCB 67-2, July 1967.

43. "Report of State and Local Radiological Health Programs - Fiscal Year 1967," U.S. Department of Health, Education, and Welfare, CCB 68-2, July 1968.

44. "Report of State and Local Radiological Health Programs - Fiscal Year 1968," U.S. Department of Health, Education, and Welfare, BRH/ORO 69-3, July 1969.

45. "Report of State and Local Radiological Health Programs - Fiscal Year 1969," U.S. Department of Health, Education, and Welfare, BRH/ORO 70-4, July 1970.

46. "Report of State and Local Radiological Health Programs - Fiscal Year 1970," U.S. Department of Health, Education and Welfare, BRH/ORO 71-2, May 1971.

47. "Report of State and Local Radiological Health Programs - Fiscal Year 1971," U.S. Department of Health, Education and Welfare, DHEW Publications (FDA) 73-8017, BRH/OBD 73-6, November 1972.

48. "Report of State and Local Radiological Health Programs - Fiscal Year 1972," U.S. Department of Health, Education and Welfare, DHEW Publications (FDA) 74-8004, August 1973.

49. "Report of State and Local Radiological Health Programs - Fiscal Year 1973," U.S. Department of Health, Education and Welfare, DHEW Publications (FDA) 75-8006, July 1974.

50. "Report of State and Local Radiological Health Programs - Fiscal Year 1974," U.S. Department of Health, Education and Welfare, DHEW Publication (FDA) 76-8017, July 1975.

51. "Report of State and Local Radiological Health Programs - Fiscal Year 1975," U.S. Department of Health, Education and Welfare, DHEW Publication (FDA) 77-8005, July 1976.

52. "Report of State and Local Radiological Health Programs - Fiscal Year 1976," U.S. Department of Health, Education and Welfare, HEW Publication (FDA) 77-8034, August 1977.

53. "Report of State and Local Radiological Health Programs - Fiscal Year 1977," U.S. Department of Health, Education and Welfare, HEW Publication (FDA) 78-8034, August 1978.

54. "A Cumulative Film Badge Readings of Licensee Employees - Statistical Data for Calendar Year 1966 - Results of Compilation by Four Film Badge Companies," U.S. Atomic Energy Commission, AEC-R 175 - Safety Record of the Atomic Energy Industry, April 13, 1968.

55. "Annual Film Badge Readings of Licensee Employees - Results of Compilations by Four Film Badge Companies for 1967," U.S. Atomic Energy Commission, AEC-R 175/1, September 26, 1968.

56. "Annual Film Badge Readings of AEC and State Licensee Employees - Results of Compilation by Three Film Badge Companies for 1968," U.S. Atomic Energy Commission, AEC-R 104/3, February 2, 1970.

57. "Annual Film Badge Readings of AEC and State Licensee Employees - Results of Complilations by Two Film Badge Companies for 1969," U.S. Atomic Energy Commission, SEC-R 269, July 23, 1971.

58. "Film Badge Reading of AEC and State Licensee Employees - Results of Compilations by Two Film Badge Companies For 1970 and 1971," U.S. Atomic Energy Commission, Note to Files: "Film Badge Study Determination" by B.H. Weiss, June 8, 1973.

59. NUREG/CR-1064 Performance Testing of Personnel Dosimetry Services, USNRC, January 1980.

60. Plato, Phillip, Progress Report No. 27, Contract No. NRC-01-77-180, March 1980.

61. Fess, L.R., "Summary of Diagnostic X-Ray Statistics Relating Facilities, Equipment, and Personnel by Healing Arts Professions," Radiological Health Data, 10:379-380, 1969.

62. Barrall, R.C. and S.I. Smith, "Personnel Radiation Exposure and Protection from Tc-99M Radiations," American Association of Physicists in Medicine (AAPM), AAPM Monograph No. 1, 1976.

63. Barrall, R.C., L.H. Lanzl and J.W. Hilbert, "A Survey of Personnel Exposure in Nuclear Medicine," Committee on Radiation Protection, American Association of Physicists in Medicine, August 3, 1975.

64. "Hospital Statistics," 1975 Edition, American Hospital Association, Chicago, 1975.

65. "A Report of the ACR Committee on Manpower - Manpower II." American College of Radiology, July 1977.

66. Ralph Bunge, Bureau of Radiological Health, unpublished data.

67. "Group Dental Practices in the United States, 1971," DHEW Publication No. (NIH) 72-189, US GPO, Washington, DC.

68. "Institutional Characteristics of U.S. Medical Schools 1975-1976," U.S. Department of Health, Education and Welfare, Health Resources Administration, Bureau of Health Manpower, DHEW Publication No. (HRA) 78-79, May 1978.

69. Grant, W.V. and C.G. Lind, "Digest of Education Statistics, 1977-78," National Center for Educational Statistics, U.S. Department of Health, Education and Welfare, 1978.

70. "Health Resource Statistics - 1975," U.S. Department of Health, Education and Welfare, DHEW Publication (HRA) 76-1509, 1976.

71. NUREG-0170 Final Environmental Statement on the Transportation of Radioactive Materials by Air and Other Modes, O.S.D, USNRC, Dec. 1977, P4-38.

72. NUREG-0154 Exposure of Airport Workers to Radiation from Shipment of Radioactive Materials, USNRC, January 1977.

APPENDIX A

THE LIST METHOD

Page

I. INITIAL APPROACH A-3

A. List Methodology A-3

B. Extrapolation Techniques A-4

II. INITIAL RESULTS A-19

III. REVISION OF LIST METHOD A-22

A. Population Estimates A-22

B. Refining Raw Commercial Exposure Data A-25

TABLES

Table	Title	Page
A-1	1975 Whole-Body Exposures Sampled from Commercial Dosimetry Service	A-6
A-2	Description of Activity Categories	A-10
A-3	Licensee Work Force for Several Categories	A-12
A-4	Licensee Work Force in Several NUCLEAR FUEL CYCLE Categories	A-13
A-5	Registrant Work Force in MEDICINE Categories	A-14
A-6	Registrant Work Force in Additional Categories	A-14
A-7	Summary of Source Data Used in List Method	A-16
A-8	Results of Extrapolations to Total Occupationally Exposed Population by Activity	A-20
A-9	Revised Version for List Method Summary	A-23

FIGURES

Figure	Title	Page
A-1	List Method Flow Diagram for California: An NRC Agreement State	A-5

I. INITIAL APPROACH

A. List Methodology

Most of the exposure data we obtained from Federal agencies were already categorized by occupation or facility. The supplemental commercial data, however, were not separable by occupation but simply listed by clients' names. We devised the List Method to select data from alphabetized lists according to whether the client was an NRC licensee or only a state registrant. Additional licensee and registrant information provided the basis for separation into occupational categories.

We selected California, Louisiana, Maryland, New York, and Texas to represent NRC Agreement States because they contained more than 50% of all Agreement State licensees. Illinois, New Jersey, Ohio, and Pennsylvania represented non-Agreement States. These latter states had more than 40% of the non-Agreement State licensees. We asked the states and NRC for lists of licensees (users of radionuclides) and registrants (users of electronic produced ionizing radiation) along with their industry or occupation. For Agreement States, we compared the state licensee list to the NRC licensee list to eliminate duplicate entries from the State list.

We originally hoped that electronic-source exposures could be separated from radionuclide exposures in the List Method. However, since NRC and NRC State Agreement licensees are required to include all exposures to workers from both electronic radiation and radioactive sources, we could not make a clean separation. We partially separated these two types of source users by comparing an Agreement State's licensee and registrant lists and placing the duplicate entries (i.e., both radioactive-source and electronic-source users) on the licensee list. This separated out the solely electronic-source users. Figure A-1 illustrates the separation procedure used for California, an NRC Agreement State.

We asked a commercial dosimetry service to compare its client list with the licensees and registrants listed in each state. From 30,000 licensee and registrant comparisons, the service matched about 10%. These provided a total sample of about 75,000 annual exposure records with designated occupations. During this procedure the service removed, as much as possible, records of badges used for area monitoring and other non-personnel monitoring purposes. The service then compiled exposure summaries for various occupational groups and for age and sex differentiation. We used this data to compute average doses and to make extrapolations for occupational categories of the national work force. Table A-1 gives a summary of the List Method data. Table A-2 describes the worker activity categories.

B. Extrapolation Techniques

We used extrapolation techniques for occupational categories where no Federal summaries existed. The commercial data provided two key inputs for these extrapolations: 1) the average number of monitored individuals per licensee, registrant, or facility, and 2) the average worker dose for an activity. We basically estimated the NRC and Agreement State licensee portion of the national work force by multiplying the number of licensees by the number of monitored individuals per licensee. Table A-3 gives data and results for several occupational categories where no other data or assumptions were necessary.

Figure A-1. LIST METHOD FLOW DIAGRAM FOR CALIFORNIA: AN NRC AGREEMENT STATE

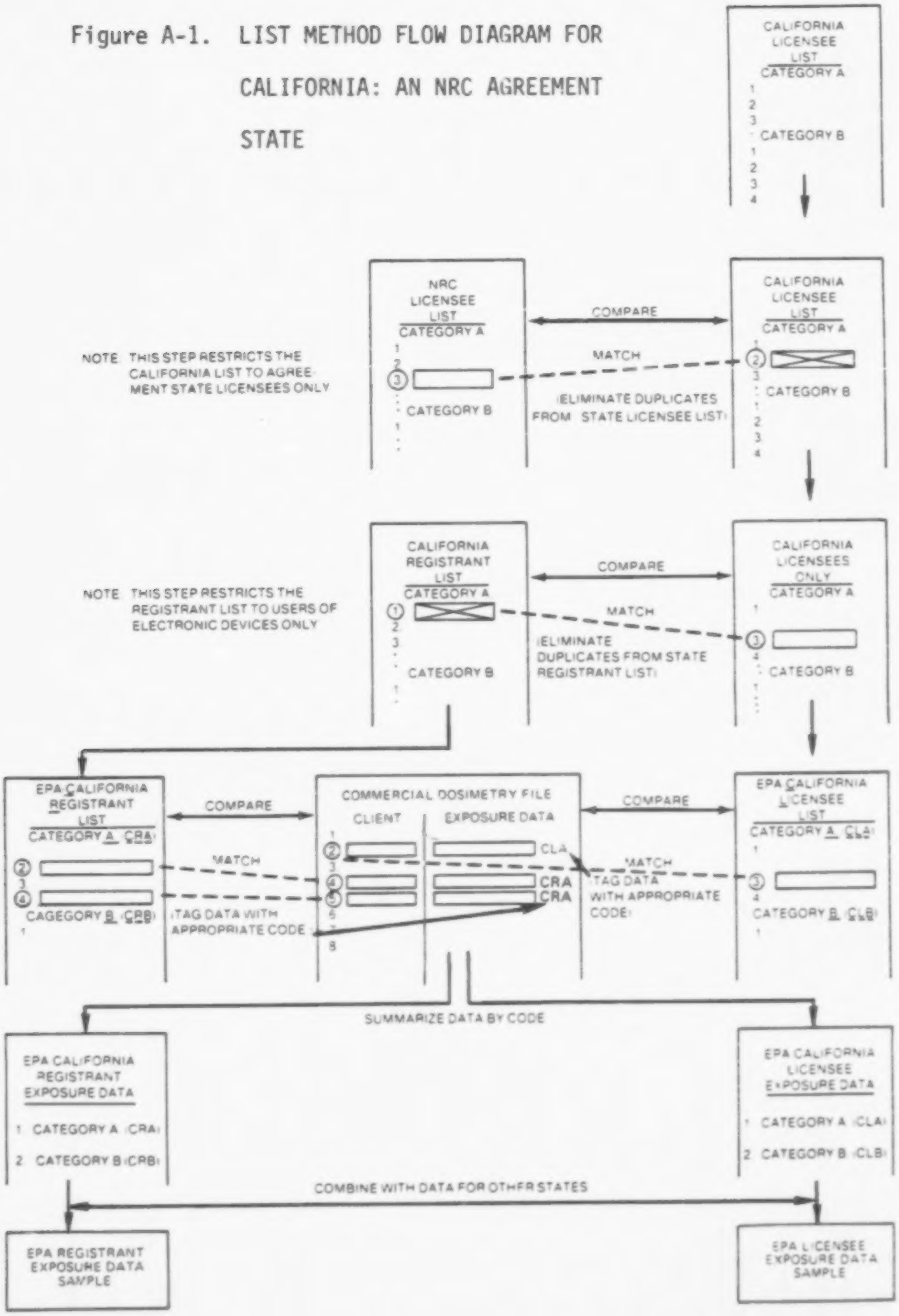

CALIFORNIA LICENSEE LIST
CATEGORY A
1
2
3
CATEGORY B
1
2
3
4
NRC LICENSEE LIST
CATEGORY A
1
2
3
CATEGORY B
1
COMPARE
MATCH
(ELIMINATE DUPLICATES FROM STATE LICENSEE LIST)
CALIFORNIA LICENSEE LIST
CATEGORY A
1
2
3
CATEGORY B
1
2
3
4
NOTE THIS STEP RESTRICTS THE CALIFORNIA LIST TO AGREEMENT STATE LICENSEES ONLY
CALIFORNIA REGISTRANT LIST
CATEGORY A
1
2
3
CATEGORY B
1
COMPARE
MATCH
(ELIMINATE DUPLICATES FROM STATE REGISTRANT LIST)
CALIFORNIA LICENSEES ONLY
CATEGORY A
1
3
4
CATEGORY B
1
NOTE THIS STEP RESTRICTS THE REGISTRANT LIST TO USERS OF ELECTRONIC DEVICES ONLY
EPA CALIFORNIA REGISTRANT LIST
CATEGORY A (CRA)
2
3
4
CAGEGORY B (CRB)
1
COMPARE
MATCH
(TAG DATA WITH APPROPRIATE CODE)
COMMERCIAL DOSIMETRY FILE
CLIENT
EXPOSURE DATA
1
2
3
4
5
6
7
8
CLA
CRA
CRA
COMPARE
MATCH
(TAG DATA WITH APPROPRIATE CODE)
EPA CALIFORNIA LICENSEE LIST
CATEGORY A (CLA)
1
3
4
CATEGORY B (CLB)
1
SUMMARIZE DATA BY CODE
EPA CALIFORNIA REGISTRANT EXPOSURE DATA
1 CATEGORY A (CRA)
2 CATEGORY B (CRB)
EPA CALIFORNIA LICENSEE EXPOSURE DATA
1 CATEGORY A (CLA)
2 CATEGORY B (CLB)
COMBINE WITH DATA FOR OTHER STATES
EPA REGISTRANT EXPOSURE DATA SAMPLE
EPA LICENSEE EXPOSURE DATA SAMPLE

Table A-1. 1975 WHOLE-BODY EXPOSURES SAMPLED FROM COMMERCIAL DOSIMETRY SERVICE

Regulatory Authority	Activity	Total Number of Workers in Sample	Mean Whole-Body Dose (millirem) (potentially exposed)	Number of Workers in Sample with Measurable Doses	Mean Whole-Body Dose (millirem) (measurably exposed)
Agreement State Registrants (California, Louisiana, Maryland, New York, Texas)	Industry	1,236	70	343	260
	Medical (Private)	871	130	381	290
	Medical (Hospital)	985	190	558	340
	Dental	562	60	113	320
	Veterinary	241	180	123	350
	Education	1,227	90	191	550
	Government	62	20	14	80
	Chiropractic	10	7	3	20
	Podiatry	41	5	7	30
	Medical (Private) Medical (Hospital) Chiropractic Podiatry	1,907	160	949	320
	All Medical & Dental	2,469	140	1,062	320
Agreement State Registrants	All Activities	5,235	110	1,733	330
Non-Agreement State Registrants (Illinois, New Jersey, Ohio, Pennsylvania)	Industry	1,801	150	467	580
	Medical (Private)	306	250	141	550
	Medical (Hospital)	728	160	426	280
	Dental	377	10	43	80
	Veterinary	59	30	19	100
	Education	587	40	123	180
	Government	58	30	10	150

Table A-1. (Continued)

Regulatory Authority	Activity	Total Number of Workers in Sample	Mean Whole-Body Dose (millirem) (potentially exposed)	Number of Workers in Sample with Measurable Doses	Mean Whole-Body Dose (millirem) (measurably exposed)
Non-Agreement State Registrants (continued)	Chiropractic	---	---	---	---
	Podiatry	13	30	4	90
	Medical (Private) Medical (Hospital) Chiropractic Podiatry	1,047	190	571	350
	All Medical	1,424	140	614	330
Non-Agreement State Registrants	All Activities	3,929	130	1,233	400
All Registrants (Agreement plus Non-Agreement States)	Industry	3,037	120	810	440
	Medical (private)	1,177	160	522	360
	Medical (hospital)	1,713	180	984	310
	Dental	939	40	156	250
	Veterinary	300	150	142	310
	Educational	1,814	70	314	410
	Government	120	20	24	110
	Chiropractic	10	7	3	20
	Podiatry	56	10	11	50
	Medical (Private) Medical (Hospital) Chiropractic Podiatry	2,954	170	1,520	330
	All Medical	3,893	140	1,676	320
All Registrants	All activities	9,164	120	2,966	360
Agreement State Licensees	Industry	3,888	210	861	970
	Medical (private)	119	140	69	240

Table A-1. (Continued)

Regulatory Authority	Activity	Total Number of Workers in Sample	Mean Whole-Body Dose (millirem) (potentially exposed)	Number of Workers in Sample with Measurable Doses	Mean Whole-Body Dose (millirem) (measurably exposed)
Agreement State Licensees (continued)	Medical (Hospital)	2,202	210	1,219	390
	Education	[illegible]	[illegible]	[illegible]	770
	Government	899	310	467	610
	Medical (Private) Medical (Hospital)	2,321	210	1,288	380
	All of the above	9,225	210	3,056	630
NRC Licensees	(1) Power Reactors	2,837	940	1,962	1,370
	(2) Fuel Fabrication	3,795	80	1,162	250
	(3) Fuel Reprocessing	113	520	86	690
	(4) Waste Disposal	23	170	8	480
	(5) Mills	90	15	23	60
	(6) Industrial Radiography	2,325	260	958	620
	(7) Manufacturing and Distribution	1,658	150	380	640
	(8) Other Industrial	8,385	310	1,405	1,850
	(9) Medical (Private)	173	150	82	330
	(10) Medical (Hosp.)	16,219	190	9,048	340
	(11) Education	13,482	110	3,614	400
	(12) Government	2,698	140	1,051	370
	Activities 4-8	12,481	280	2,774	1,240
	Activities 4-12	45,053	190	16,569	500

Table A-1 (Continued)

Regulatory Authority	Activity	Total Number of Workers in Sample	Mean Dose (mrem) (potentially exposed)	Number of Individuals in Sample with Measurable Doses	Mean Dose (mrem) (measurably exposed)
Selected Agreement States and NRC Licensees combined	Industry-Agreement States and NRC Activities 4-8	16,369	260	3,631	1,180
	Medical (Private)	292	150	151	290
	Medical (Hospital)	18,421	190	10,267	340
	Education	15,599	110	4,054	440
	Government	3,597	190	1,058	640
	Medical (Private) Medical (Hospital)	18,713	190	10,418	340
All of the above selected combinations		54,278	190	19,615	520
Miscellaneous					
ERDA	Research and Development	599	9	94	60
BRH	Manufacturing and Distribution	469	710	98	3,400
Entire Sample	ALL	77,515	210	29,041	550

Table A-2. DESCRIPTION OF ACTIVITY CATEGORIES*

Activity	Brief Description
a. Medical Hospital/Clinic Private Practice	All medical use of electronic and radionuclide sources of radiation in hospital/clinic or private practice, excluding categories "b-e" below.
b. Dental	Use of x-ray machines in the practice of dentistry.
c. Podiatry	Use of x-ray machines in the practice of podiatry.
d. Chiropractic	Use of x-ray machines in the practice of chiropractic medicine.
e. Veterinary	Use of x-ray machines in the practice of veterinary medicine.
f. Industrial Radiography (Radionuclides)	Facilities which use radionuclides purposes of radiography (i.e., non-destructive testing).
g. Other Industrial (Radionuclides)	Facilities which utilize or handle radionuclides other than categories "f-h" above, including industrial R&D.
(Electronic Sources)	Industrial facilities which utilize electronic sources of radiation (i.e., x-ray machines), other than category "h" below, including industrial R&D.
h. Manufacturing & Distribution	Facilities which produce or distribute radionuclides for commercial application (i.e., radiopharmaceuticals).
(Electronic Sources)	Facilities which produce or distribute electronic sources of radiation (i.e., x-ray machines).
i. Nuclear Power Reactors	All reactors subject to reporting requirements in 10 CFR 20.

Table A-2 (Continued)

j.	Nuclear Fuel Fabrication and Reprocessing	Facilities for the production of fuel assemblies used in reactors and for the chemical processing of fuel from reactors.
k.	Nuclear Waste Disposal	Facilities for the handling, treatment, and burial of nuclear radioactive wastes.
l.	Uranium Mills	Facilities for the extraction of uranium oxide from uranium ore.
m.	Uranium Enrichment	Facilities for the isotopic enrichment of uranium.
n.	Government (Radionuclides)	Use of radionuclides for government functions, including Public Health Service exposures (i.e., civil defense). VA hospitals included in this category. Government R&D included in category "p" below. Military included in category "o" below.
	(Electronic Sources)	Use of electronic sources of radiation (i.e., x-ray machines) for government functions (i.e., civil defense). VA hospitals included in this category. Government R&D included in category "o" below.
o.	Military	All Army, Navy, and Air Force exposures to ionizing radiation.
p.	Research and Development	Exposures to ionizing radiation from government-sponsored R&D.
q.	Education	Use of radionuclide and electronic sources of radiation for educational purposes. University hospitals included in category "a" above.

*Source: Occupational Exposures to Ionizing Radiation Within the United States for the Year 1975, Phase II Report, Prepared by Teknekron, Inc.

Table A-3. LICENSEE WORK FORCE FOR SEVERAL CATEGORIES

Category	Workers Monitored Per Licensee	Number of Licensees	Number of Workers
Medicine			
Hospital/Clinic	35.8	3,284	117,567
Private Practice	6.6	2,022	13,345
Other Industrial	21.0	5,432	114,072
Education	77.2	829	63,999

The industrial radiography category could not be separately identified in the commercial data. However, the NRC had 345 industrial radiography licensees for which 9178 workers were monitored, representing an average of 26.6 workers per licensee. NRC Agreement State data showed 399 facilities but not the number of workers. We assumed that the number of workers per licensee derived for just NRC radiography licensees applied to all such licensees, yielding 26.6 x (345 + 399) = 19,790 total workers.

The manufacturing and distribution category was treated similarly to the radiography category, but with additional assumptions. We again derived the number of workers per licensee from NRC data: 3,367 workers for 307 licensees gives 11.0 workers per licensee. The number of similar licensees in the Agreement States was unknown. We assumed that the ratio of NRC to Agreement State licensees was the same for this activity as it was for the entire industrial category (i.e. 2945/3173). This assumption yields 330 Agreement State licensees. These were added to the 307 licensees to give a total of (307 + 330) x 11.0 = 7,000 workers.

Waste disposal and uranium mill licensees are not required to report their worker exposure summaries to the NRC. We estimated these worker populations by combining commercial and NRC data as summarized in Table A-4.

Table A-4. LICENSEE WORK FORCE IN SEVERAL NUCLEAR FUEL CYCLE CATEGORIES

Category	Number of Workers per Facility (commercial data)	Number of Facilities (NRC data)	Number of Workers
Waste Disposal	7.7	40	308
Uranium Mills	15.0	17	255

We similarly estimated the number of workers in the government (radionuclide) activity (primarily employed by Civil Defense and Veterans Administration licensees); 30.3 workers per facility (commercial data) multiplied by 322 licensees (NRC data) yields 9,757 workers. Exposure data from the Bureau of Radiological Health was believed to provide the best estimate of mean dose for this category.

For medical categories that used electronic product radiation sources, we relied on Fess information that related x-ray facilities, equipment, and personnel (61). Although the overall number of diagnostic x-ray machines increased, there appeared to be no major changes to general patterns of persons operating x-ray machines between 1965 and 1975. We again calculated the average number of monitored persons per facility from the commercial data. We estimated the number of facilities by dividing the number of machines reported by the Food and Drug Administration (FDA) by the Fess number of x-ray machines per facility. The product of the estimated workers per facility and the derived number of facilities yielded the estimated work force. See Table A-5.

Table A-5. REGISTRANT WORK FORCE IN MEDICINE CATEGORIES.

Activity	Number of Machines	Machines per Facility	Number of Facilities	Workers per Facility	Number of Workers
Medical					
Private Practice	40,225	1.16	34,677	3.1	107,499
Hospital/ Clinic	49,632	4.53	10,956	6.0	65,736
Dental	139,607	1.10	126,915	3.7	469,586
Podiatry	4,775	1.00	4,775	3.0	14,325
Chiropractic	11,566	1.00	11,566	1.7	19,662
Veterinary	7,972	1.05	7,592	6.1	46,311

We used the commercial data identified in state registrant lists to calculate additional populations exposed to electronic product radiation sources. The "other industrial" category, which includes industrial radiographers using only x-ray type sources, had an average of 9.0 workers per facility. We estimated 7,390 facilities to be using x-ray devices in the non-healing arts. This included educational and governmental as well as industrial facilities (51). Based on the combined NRC and NRC Agreement State licensees for these categories, we estimated that 85%, 11%, and 4% of the 7390 facilities were Other Industrial, Government, and Education, respectively. The projected results are given in Table A-6.

Table A-6. REGISTRANT WORK FORCE IN ADDITIONAL CATEGORIES

	Persons per Facility	Number of Facilities	Number of Persons
Other Industrial	9.0	6,281	56,529
Government	8.0	296	2,368
Education	47.7	813	38,780

The last remaining activity concerns exposures associated with the manufacturing and distribution of electronic sources of radiation. The commercial data provided a ratio of 9.0 workers per facility. When this was multiplied by an estimated 440 facilities, we obtained a work force estimate of 3,960 workers.

The accuracy of the above work force extrapolations, where no government summaries existed, was dependent on the commercial data sample. The size of the commercial data sample for some categories was uncomfortably small, and we have correspondingly less confidence in those results. Table A-7 summarizes the source data from Federal and State Licensee/Registrant listings. The numbers of whole-body exposure records available from the commercial dosimetry sample and government summaries are given in Table A-7.

Table A-7. SUMMARY OF SOURCE DATA USED IN LIST METHOD*

CATEGORY	Number of NRC and Agreement State Licensees submitted for analysis (Radionuclide sources)	Number of State Registrants submitted for analysis (Electronic sources)	Number of Whole-Body Records in Data Sample: Commercial Dosimetry	Number of Whole-Body Records in Data Sample: Government Summary	Category Description or Type of Professional Personnel Involved
MEDICINE					
Hospital/Clinic and Private Practice					
Radionuclide sources	(1)	---	18713	---	Physicians, Nurses, technologists, technicians and therapists
Electronic sources	---	5560	2890	---	
Dental	(1)	8619	939	---	Dentists, dental technologists and assistants
Podiatry	(1)	1050	54	---	Podiatrists and assistants
Chiropractic	(1)	1833	10	---	Chiropractors and assistants
Veterinary	(1)	1628	300	---	Veterinarians & veterinary assts.
SUBTOTAL	2957	18690	22906	---	
INDUSTRY					
Industrial Radiography	280	(2)	2325**	9178	Facilities which use radiation sources for purposes of radiography (i.e., non-destructive testing)
Manufacturing & Distribution Radionuclide sources	240	---	1658	3367	Facilities which produce or distribute radionuclides for commercial use (e.g., radiopharmaceuticals)
Electronic Sources	---	(2)	469	---	Electronic sources of radiation (e.g., x-ray machine)
Other Industrial					Industrial facilities which utilize electronic and radionuclide sources not included in the Industrial Radiography, Manufacturing and Distribution categories above, or the Nuclear Fuel Cycle categories below
Radionuclide sources	4025	---	12273	---	
Electronic sources	---	(2)	3037	---	
SUBTOTAL	4545	2500	19762	12545	

Table A-7. (Continued)

CATEGORY	Number of NRC and Agreement State Licensees submitted for analysis (Radionuclide sources)	Number of State Registrants submitted for analysis (Electronic sources)	Number of Whole-Body Records in Data Sample		Category Description or Type of Professional Personnel Involved in Activity
			Commercial Dosimetry	Government Summary	
NUCLEAR FUEL CYCLE					
Nuclear Power Reactors	220	---	2837**	54763	All reactors subject to reporting requirements (10 CFR 20)
Nuclear Fuel Fabrication and Processing	18	---	3908**	11405	Facilities for the production of fuel assemblies used in reactors and chemical processing of fuel from reactors
Nuclear Waste Disposal	9	---	23	---	Facilities for the handling, treatment and burial of radioactive waste
Uranium Mills	14	---	90	---	Facilities for the extraction of uranium oxide from uranium ore
Uranium Enrichment	---	---	---	7471	Facilities for the isotope enrichment of uranium
SUBTOTAL	261	---	6858	73639	
GOVERNMENT					
Department of Energy	(3)	(3)	599**	84940	Personnel exposed to ionizing radiation from government sponsored research and development
Department of Defense	(3)	(3)	---	81346	Army, Navy, and Air Force personnel
Government					Use of radionuclide and electronic sources of radiation for government functions: Civil Defense, Public Health Service, and VA Hospitals included in this category
Radionuclide sources	895	---	3597	2392	
Electronic sources	---	655	120	---	
SUBTOTAL	895	655	4316	168678	
EDUCATION					
Radionuclide sources	755	---	15599	---	Use of radionuclide and electronic sources of radiation for educational purposes, University hospitals and clinics are included in Medicine category
Electronic sources	---	695	1814	---	
SUBTOTAL	755	695	17413	---	

Table A-7. (Continued)

CATEGORY	Number of NRC and Agreement State Licensees submitted for analysis	Number of State Registrants submitted for analysis	Number of Whole-Body Records in Data Sample		Category Description or Type of Professional Personnel Involved in Activity
	(Radionuclide sources)	(Electronic sources)	Commercial Dosimetry	Government Summary	
TOTALS	9413	22540	71255**	254862	

(1) Radionuclide sources licensed to Dentists, Podiatrists, Chiropractors, Veterinarians, Private Practice and Hospital/Clinic medical practice are included in the total of of 2957.

(2) No detailed assignment of electronic source registrants for the designated Industrial categories.

(3) Number of radionuclide and electronic sources of radiation not given.

*Source: Occupational Exposures to Ionizing Radiation Within the United States in the Year 1975, Phase II Report, Prepared by Teknekron, Inc.

**Some whole-body records are also contained in government summary. Thus, the total number of records utilized for data analysis is less than the sum of individual records contained in the government summary and commercial dosimetry sample.

II. INITIAL RESULTS

Table A-8 shows the initial results of the List Method for 24 occupational activities. The estimated number of workers and average dose are given for the "total" workers potentially exposed to radiation and for the "exposed" workers projected to receive measurable doses. The summary shows 1,410,800 "total" and 470,563 "exposed" workers, with mean doses of 130 and 410 mrem, respectively, and a collective dose of 185,384 person-rems. The Dental group was the largest single component of the radiation work force, with about 470,000 persons. The Other Industrial (Radionuclides) activity had the largest collective dose, about 32,000 person-rems. The group with the largest average dose was Manufacturing and Distribution (Electronic Source).

Table A-8. RESULTS OF EXTRAPOLATIONS TO TOTAL OCCUPATIONALLY EXPOSED POPULATION BY ACTIVITY#

Activity	Projected Number of Workers*	Mean Whole-Body Dose (rem)**		Collective Dose (person-rems)
Nuclear Power Reactors	54,763 (28,034)	.39	(.76)	21,400
Nuclear Fuel Fabrication & Reprocessing	11,405 (5,495)	.27	(.56)	3,100
Nuclear Waste Disposal	308 (105)	.17	(.48)	50
Uranium Mills	255 (65)	.015	(.06)	4
Uranium Enrichment	7,471 (5,664)	.051	(.071)	400
Industrial Radiography (Radionuclides)	19,816 (8,165)	.30	(.72)	5,900
Manufacturing and Distribution (Radionuclides)	7,000 (3,865)	.35	(.65)	2,500
Other Industrial (Radionuclides)	114,072 (25,330)	.28	(1.26)	31,900
Manufacturing and Distribution (Electronic Sources)	3,960 (825)	.71	(3.4)	2,800
Other Industrial (Electronic Sources)	56,529 (15,100)	.12	(.45)	6,800
Medical (Radionuclides)				
Private Practice	13,345 (6,900)	.15	(.29)	2,000
Hospitals/Clinics	117,567 (65,525)	.19	(.34)	22,300

---

*Number in parentheses is projected (or, in some cases, actual) number of workers with measurable exposure.

**Number in parentheses is mean whole-body dose for those receiving measurable doses.

#Source: Occupational Exposures to Ionizing Radiation Within the United States for the Year 1975, Phase II Report, Prepared by Teknekron Research, Inc. July 7, 1978. Several minor arithmetic corrections were made in this table from the original.

Table A-8. (Continued)

Activity	Projected Number of Workers*	Mean Whole-Body Dose (rem)**	Collective Dose (person-rems)
Medical (Electronic Sources) Private Practice	107,499 (28,670)	.16 (.60)	17,200
Hospitals/Clinics	65,736 (37,760)	.18 (.31)	11,800
Dental	469,586 (78,015)	.04 (.24)	18,800
Podiatry	14,325 (2,920)	.010 (.05)	140
Chiropractic	19,662 (5,900)	.007 (.02)	140
Veterinary	46,311 (21,600)	.15 (.32)	6,900
Education (Radionuclides)	63,999 (16,630)	.11 (.42)	7,000
Education (Electronic Sources)	38,780 (6,710)	.07 (.4)	2,700
Government (Radionuclides)	9,757 (4,090)	.19 (.46)	1,900
Government (Electronic Sources)	2,368 (475)	.02 (.11)	50
Military	81,346 (62,626)***	.095 (.123)	7,700
Research and Development	84,940[+] (40,094)	.14 (.30)	11,900
TOTAL	1,410,800 (470,563)	.13 (.41)	185,384

*Number in parentheses is projected number of workers with measurable exposure.

**Number in parentheses is mean whole-body dose for those receiving measurable doses.

***Number of workers with measurable exposure is relatively large because Navy did not use a less-than-measurable range.

[+] ERDA enrichment workers have been eliminated from the Research and Development activity to form the Uranium Enrichment category. Visitors to ERDA facilities have also not been excluded.

III. REVISION OF LIST METHOD

The List Method findings shown in Table A-8 resulted from a purely systematic approach: multiplying numbers of facilities by numbers of persons per facility and multiplying the resulting extrapolated populations by average doses to obtain collective doses. In reviewing these results, we found that the sizes of some professional work force groups were much larger than estimates by professional associations. We also questioned the representativeness of some of the commercial dose data.

Table A-9 is a revised version of the List Method summary. The results are re-grouped into five major categories: MEDICINE, INDUSTRY, NUCLEAR FUEL CYCLE, GOVERNMENT, and EDUCATION. Population and collective dose estimates are rounded to the nearest 100 persons and 100 person-rems, respectively, while average doses are rounded to the nearest 10 mrem.

A. Population Estimates

Two of the initial population estimates in MEDICINE (Table A-8), for Dental and Veterinary, were considerably larger than estimates from corresponding professional associations. The persons-per-client ratio used from the commercial data was probably larger than the true ratio, because larger facilities were more likely than smaller facilities to provide personnel monitoring. This would lead to an overestimate of the work force size. We brought the Dental population into closer agreement with American Dental Association data by replacing the 3.7 persons per facility derived from the List Method sample by a 2.5 value from age-only records of the commercial sample. Our assumption here is that records

Table A-9. REVISED VERSION FOR LIST METHOD SUMMARY

Activity	Extrapolated Population[a]		Mean Whole-Body Dose[b] (millirem)		Collective Dose[c] (person-rems)
	Total	Exposed	Total	Exposed	
MEDICINE[d]:					
Hospital/Clinic					
Licensees	117,600	65,500	190	340	22,100
Registrants	65,700	37,800	190	330	12,500
Private Practice					
Licensees	13,300	6,900	160	300	2,100
Registrants	107,500	28,700	100	370	10,600
Dental	342,700	56,900	30	170	9,900
Podiatry	14,300	2,900	10	30	100
Chiropractic	19,700	5,900	-	10	100
Veterinary	22,800	10,800	200	420	4,500
SUBTOTAL	703,600	215,400	90	290	62,000
INDUSTRY[d]:					
Industrial Radiography					
Licensees	19,800	9,700	290	580	5,700
Industrial Users					
Licensees	114,100	18,800	100	610	11,400
Registrants	55,900	16,000	110	370	5,900
Manufact. & Distrib. of Radiation Sources					
Licensees	7,000	3,900	350	630	2,500
Registrants	4,000	800	40	200	200
SUBTOTAL	200,800	49,200	130	520	25,600
NUCLEAR FUEL CYCLE:					
Nuclear Power Reactors[e]	54,763	28,034	390	760	21,400
Nuclear Fuel Fabrication & Reprocessing[e]	11,405	5,495	270	560	3,100
Nuclear Waste Disposal[f]	300	100	310	920	100
Uranium Mills	300	100	20	50	-
Uranium Enrichment[e]	7,471	5,664	50	70	400
SUBTOTAL	74,200	39,400	340	630	24,900

Table A-9. (Continued)

Activity	Extrapolated Population[a] Total	Extrapolated Population[a] Exposed	Mean Whole-Body Dose[b] (millirem) Total	Mean Whole-Body Dose[b] (millirem) Exposed	Collective Dose[c] (person-rems)
GOVERNMENT[d]:					
Department of Energy[e]	80,954	39,451	150	300	11,800
Department of Defense	92,500	55,800	110	180	10,100
Other Government					
Licensees	9,800	4,100	170	400	1,600
Registrants	2,400	500	30	120	100
SUBTOTAL	185,700	99,900	130	240	23,500
EDUCATION[d]:					
Licensees	64,000	16,600	80	290	4,900
Registrants	38,800	6,700	70	380	2,600
SUBTOTAL	102,800	23,300	70	320	7,400
TOTAL	1,267,100	427,200	110	340	143,500

[a] The left column is the projected or actual "total" number of radiation workers in each activity. The right column is the projected number of "exposed" individuals who receive a measurable dose.

[b] The mean doses correspond to the populations in the first two columns.

[c] The collective dose is the product of the extrapolated "total" population and the corresponding mean dose. The mean dose for those "exposed" is the quotient of the collective dose and the extrapolated "exposed" population. Collective dose values are rounded to the nearest 100 person-rem while mean doses are rounded to the nearest 10 mrem. The total and subtotal values of collective dose were obtained from non-rounded subcategory activities before rounded.

[d] "Licensee" refers to NRC and NRC agreement state licensees for use of radionuclides. Because of NRC monitoring requirements, dose to these workers from electronic radiation sources is also included. "Registrant" refers to state registrants, who have only electronic radiation sources.

[e] Populations are exact for these primarily research and development activities since complete records on the entire workforce are available.

[f] Mean whole body dose value based on Analysis of Burial Ground Operational Exposure Experience (Table III, Appendix H) of NUREG-0216, The Environmental Survey of the Reprocessing and Waste Management Portions of the LWR Fuel Cycle, U.S. Nuclear Regulatory Commission, March 1977.

with age information correspond to actual persons and not to area type monitoring. This decreased the dental population estimate by about 125,000 persons. Based on data from the American Veterinary Medical Association, we decreased the Veterinary to about half. The revised List Method population is thus 1.26 million "total" with about 427,000 "exposed".

B. Refining Raw Commercial Data

The average doses calculated from commercial data were much higher for some occupations than those given by government summaries for the same activities. We examined the commercial data and found 70 out of 75,000 records with exposures in the 12+ rem range. The government data contained only 3 out of 250,000 records in the 12+ rem range. We found that 25% of the total collective dose from the commercial data was due to the 70 reported doses of more than 12 rem. Furthermore, the average dose for these 12+ rem records was over 40 rem; two records in the industrial radiography category accounted for over 1300 rem. We concluded that the raw commercial data contained anomalous records.

We examined several methods for eliminating anomalous records in the commercial data base. One method was to establish a dose limit beyond which records would be considered erroneous, and therefore deleted. But, such a limit would be arbitrary. Morever, it was likely that some 12+ rem records in the commercial data were accurate.

We found that 85% of the collective dose for records over 12 rem occurred in records that did not have birthdate data. Assuming that clients are more likely to "spike" dosimeters or monitor high radiation areas with dosimeters not actually assigned to workers, and that these dosimeters are less likely to have birthdate coded records, we recalculated average doses after eliminating non-birthdate coded records over 12 rem. Non-birthdate coded records under 12 rem were not eliminated because comparison of average doses for birthdate and non-birthdate coded records under 12 rem agreed to within a few millirem. Although this correction method does not assure an accurate data base, we believe it provides more reliable information than do summaries based simply on the raw commercial data.

We obtained a 15% overall reduction in average dose for the commercial data by omitting the non-birthdate coded records over 12 rem. The largest changes in average dose occurred in the Manufacturing and Distribution (Electronic Sources) and Other Industrial (Radionuclide) categories. The average doses for the "total" and "exposed" populations for the former activity were reduced from 710 to 40 mrem and 3,400 to 200 mrem, respectively. The "total" and "exposed" averages for the Other Industrial category, which included the two records totalling 1300 rem, fell from 280 to 110 mrem and from 1,260 to 440 mrem, respectively, with an associated decrease in collective dose of 19,400 person-rems.

The combination of smaller population sizes and average doses in the revised summary decreased the estimated collective dose for the work force from about 185,000 to about 142,000 person-rems. The total population decreased from 1.41 to 1.26 million workers. Despite improvements, we concluded that the List Method still generally overestimated population sizes. For the INDUSTRY category, however, we believe that the population extrapolation from the List Method is superior to the Code Method given in Appendix B.

APPENDIX B

THE CODE METHOD

Page

I. INITIAL APPROACH B-3

II. INITIAL RESULTS B-4

III. REVISION OF CODE METHOD B-8

  A. Bias of Commercial Data B-8

  B. Category Revisions B-9

    1. Medical B-9

      a. Hospital B-9

      b. Private Practice B-10

    2. Academic B-13

    3. Government B-13

    4. Industry B-13

    5. Nuclear Fuel Cycle B-14

IV. REVISED CODE METHOD RESULTS B-15

LIST OF TABLES

Table	Title	Page
B-1	Initial Code Method Exposure Summary	B-5
B-2	Workers Potentially Exposed in the Healing Arts to Electronic Ionizing Radiation Sources in 1975	B-11
B-3	Revised Code Method Occupational Exposure Summary for 1975	B-16

I. INITIAL APPROACH

In the Code Method we used about 200,000 exposure records from a commercial dosimetry service to represent occupations not included in Federal summaries. This was possible because the commercial data could be sorted and summarized according to an occupational classification system developed by the dosimetry service after we started to use the List Method approach. This is in contrast to the List Method; after matching clients with licensee and registrant lists from nine states and the NRC, we could only classify 75,000 of the service's whole-body exposure records.

As with the List Method, we calculated the average number of persons per facility and the average dose for monitored workers from the commercial data to extrapolate to national figures. Since the Code Method results are based on the entire data base of the commercial firm, we cannot release the intermediate work force calculations without compromising proprietary marketing information. We therefore present the initial Code Method population estimates without explicitly showing their derivation.

We again found that some worker estimates based on persons-per-facility ratios did not agree with personnel resource data of professional groups. These will be treated in Section III on Revision of Code Method.

II. INITIAL RESULTS

We divided the commercial dosimetry data into seven major groups: Hospital, Private Practice, Academic, Industrial, Services, Utilities, and Government. Within these seven groups there were 52 client code categories.

Table B-1 shows the initial Code Method exposure summary by group and category. We have added a Federal Summaries section to the table for government occupational groups that do not generally use commercial dosimetry services. There is no need to attempt extrapolations of these groups from limited commercial data, because most government agencies have complete personnel exposure summaries.

Based on the Code Method, there were 1.4 million persons in the 1975 radiation work force, with about 460,000 exposed; they received average doses of 100 and 310 mrem respectively and a total collective dose of about 140,000 person-rems. These population figures are very close to those for the unrevised List Method (Table A-8). Since the List Method extrapolations were also based on persons-per-facility ratios derived from a subset of the Code Method data, this might be expected. However, this excellent overall comparability is not reflected in some occupational groups. For example, the nuclear power plant data in the Code Method projects a population of only 8,700 persons; we used the 55,000 reported by NRC in the List Method. The Dental group is projected at almost 515,000 persons, 45,000 higher than the initial List Method results. We therefore found it necessary to modify these Code Method results to provide agreement with personnel resource data.

TABLE B-1. INITIAL CODE METHOD EXPOSURE SUMMARY FOR 1975

Occupational Group Description	Extrapolated Population[a] Total	Extrapolated Population[a] Exposed	Mean Whole-Body Dose[b] (millirem) Total	Mean Whole-Body Dose[b] (millirem) Exposed	Collective Dose[c] (person-rems)
* HOSPITALS *					
Gen. Med. & Surgical	120,000	72,000	250	420	30,360
Inst.(Prison,college)	530	210	60	140	30
Psychiatric	2,870	600	20	100	60
T.B. or Respiratory	110	40	60	160	10
Other specialties	3,600	1,150	50	160	180
Childrens Specialties	1,830	550	50	170	90
Universities(not infirm)	25,150	10,310	130	310	3,170
Subtotal	154,090	84,860	220	400	33,900
* PRIVATE PRACTICE *					
Physician	137,380	50,830	160	450	22,650
Dental	513,590	80,120	20	140	11,300
Veterinarian	34,120	11,600	80	230	2,660
Osteopathic	3,160	840	50	180	150
Chiropractic	29,170	7,330	30	110	820
Radiologists	14,660	8,800	180	290	2,580
Cardiologists	450	140	10	40	-
Specialists(urology,etc.)	11,900	3,770	70	220	840
Medical X Ray	6,270	3,620	300	520	1,890
Med.Labs,blood banks,etc.	6,250	1,270	60	280	360
Sanitariums,nurs.homes,etc.	2,770	1,470	80	150	220
Subtotal	759,720	169,790	60	270	43,480
* INDUSTRIAL *					
Manufacturing-General	29,980	6,300	60	290	1,800
Metals/Metal Products	26,120	8,620	120	360	3,090
Forge	740	320	330	770	250
Electronic Eqp&Appliances	41,180	9,060	90	400	3,580
Instruments/Gauges	13,980	2,100	40	240	490
Office Equip(Incl.computers)	2,750	200	-	30	10
Oil Prod.& Refineries	2,580	250	10	100	30
Mining	940	360	20	50	20
Transp/Farm Eqp.	11,470	3,210	90	340	1,080
Aerospace	7,130	6,270	110	130	800
Rubber/Plastic Products	3,770	130	-	100	10
Chemicals	12,170	800	10	170	130
Drugs/Pharmaceuticals	2,900	410	10	70	30

Table B-1. (Continued)

Occupational Group Description	Extrapolated Population[a] Total	Extrapolated Population[a] Exposed	Mean Whole-Body Dose[b] (millirem) Total	Mean Whole-Body Dose[b] (millirem) Exposed	Collective Dose[c] (person-rems)
Radiopharmaceuticals	6,550	2,420	110	300	730
Food Proc./Bev/Tobacco	860	260	80	250	70
Nuclear Fuels	4,390	1,800	30	70	120
Construction	700	200	150	530	110
Engineers/Consultants	4,450	1,600	210	590	940
Research/Res.Labs & R&D	17,740	3,370	120	610	2,060
Ind.Radiographers, etc.	17,890	10,200	550	960	9,790
Plant Med. Facility	3,600	430	40	330	140
Foundry/Castings	2,240	400	80	460	190
Subtotal	214,130	58,710	120	430	25,440
* SERVICES *					
Insurance	600	20	-	20	-
Transportation/freight	20,150	3,220	30	190	600
Airport Security	5,280	630	10	60	40
Resale/Dist.X-Ray Eqp.	15,060	5,870	130	340	2,020
Subtotal	41,090	9,740	60	270	2,660
* UTILITIES *					
Nuclear Power Plants	8,630	5,350	840	1,360	7,270
Conventional Power, etc.	430	140	60	200	30
Subtotal	9,060	5,490	810	1,330	7,290
* GOVERNMENT *					
Federal	1,630	210	10	90	20
State	3,800	1,140	40	140	160
Local	2,850	770	190	720	550
Subtotal	8,280	2,120	90	350	730
* ACADEMIC *					
University or college	49,260	14,290	80	260	3,740
Jr. or Comm. college	4,800	2,160	60	120	260
Grade, high or private	200	20	-	-	-
Tech.(nursing,mech,etc.)	2,380	760	60	180	140
Subtotal	56,640	17,210	70	240	4,140
Non-Federal Total	1,243,010	353,380	90	330	117,640

Table B-1. (Continued)

Occupational Group Description	Extrapolated Population[a]		Mean Whole-Body Dose[b] (millirem)		Collective Dose[c] (person-rems)
	Total	Exposed	Total	Exposed	
FEDERAL SUMMARIES:					
Uranium Enrichment (DOE)	7,471	5,664	50	70	380
Military	92,500	55,800	110	180	10,070
Veterans Administration	7,000	2,300	150	460	1,050
Research & Develop. (DOE)	80,954	39,451	150	300	11,780
Subtotal	187,925	103,215	120	230	23,290
TOTAL	1,430,935	456,595	100	310	140,930

---

[a] The left column is the projected or actual "total" number of potentially exposed individuals in each activity. The right column is the projected or actual "exposed" number of individuals who received a measureable dose.

[b] The mean doses correspond to the populations in the first two columns.

[c] The collective dose is the product of the extrapolated total population and the corresponding mean dose. The mean dose for those exposed is the quotient of the collective dose and the extrapolated exposed population. Collective dose values are rounded to the nearest 10 person-rem, while mean doses are rounded to the nearest 10 mrem. The Total and Subtotal values of collective dose were not obtained from rounded individual subcategory activities.

III. REVISION OF CODE METHOD

The major drawback to use of the detailed occupational breakdown of exposure data in the Code Method was lack of corresponding detailed work force estimates. Therefore, we recombined code categories to levels where work force data were available. These levels were basically the NRC program code description for its special and byproduct licensees, and the registration classification used by state radiological health programs for electronic radiation sources. These occupational groupings were also used in the List Method, but in that approach we generally based extrapolations on information derived from the commercial data. In the revised Code Method, we relied even more on published information of professional manpower and institutional studies.

A. Licensee and Registrant Data

The NRC, with Agreement State data included, biannually summarizes the number of licenses. The NRC has 10 licensee categories for byproduct material use: academic; private practice; other medical; measuring systems; manufacturing, distribution and service; radiography; irradiators; research and development; civil defense; and others. The Food and Drug Administration annually compiles information from states on the number of registered electronic sources of ionizing radiation, i.e., x-ray machines and particle accelerators. These annual reports provide the number of diagnostic medical x-ray units in the following types of facilities: hospital, clinic, x-ray truck, physician, chiropractor, veterinarian, podiatrist, and others.

B. Category Revisions

1. Medical

a. Hospitals

The number of diagnostic x-ray machines in hospitals and other types of facilities are documented in the annual "Report of State and Local Radiological Health Programs." Data for 1975 showed about 42,500 x-ray machines for hospitals (51). We multiplied this number of machines by the number of occupationally exposed workers per x-ray machine, determined in the Fess study, to give an estimate of 47,000 workers. This does not include workers exposed to radionuclide sources.

Two studies of personnel exposures in nuclear medicine indicated an average of 7.2 workers for 47 hospitals averaging 561 beds (62,63). In 1975, approximately 3,200 hospitals/clinics had diagnostic radioisotope capability (32). We therefore estimated that approximately 23,000 workers were exposed as a result of diagnostic nuclear medicine procedures. From 1975 hospital statistics, we find approximately 1,800, 1,400, and 1,000 hospitals had therapeutic radioisotope, radium therapy, and cobalt therapy facilities, respectively (64). We assumed that the average number of workers per hospital for each of these radionuclide uses was the same as that for nuclear medicine, yielding approximately 30,000 additional workers. This gives a total of 100,000 workers exposed from all uses of radiation in hospitals.

The earlier estimate of 157,000 persons occupationally exposed in hospitals (Table B-1) was considerably larger than the 100,000 determined here. In that estimate we assumed that: (1) the number of dosimeters used by each commercial customer equals the number of potentially exposed workers, and (2) hospitals using the commercial service are representative of all U.S. hospitals. We believe the latter assumption to be the weakest. Small hospitals will tend to have the minimum necessary radiation sources with little or no personnel monitoring. Hospitals using a dosimetry service are likely to be larger than average and have more workers involved with each type of radiation source.

b. Private Practice

To estimate the amount of radiation exposure in private medical practices, we followed an approach similar to that used for hospitals. In 1975, physicians, clinics, and others (including x-ray vans but excluding academic or educational devices) had approximately 43,380, 9,360 and 3,990 diagnostic machines, respectively, for a total of 56,730 (51). Assuming 1.16 x-ray machines per facility (61), we obtain 48,905 facilities in total.

A report of the American College of Radiology Committee on Manpower stated that 11,283 active, non-Federally employed, radiologists practiced in 1974-75 and that, of these, 10,583 practiced in diagnostic or therapeutic radiology (65). There were 6,985 radiologists in 1,058 group practices (6.6 radiologists per group). We assumed the remaining 3,598 radiologists to be solo practitioners. This yielded a total of 4,656 practices or facilities. The 4.29 persons-per-radiology facility provided by Fess yielded 19,970 radiologists and associated workers. We similarly used the Fess data to revise the estimates of other potentially exposed worker populations in the healing arts as shown in Table B-2.

Table B-2. WORKERS POTENTIALLY EXPOSED IN THE HEALING ARTS TO ELECTRONIC IONIZING RADIATION SOURCES IN 1975

Group	Number of Units[a]	Units per Facility[b]	Number of Facilities	Workers per Facility[b]	Number of Workers
Radiologists	---	---	4,656[c]	4.29	19,970
Physicians	56,730[d]	1.16	44,249[e]	2.33	103,100
Dentists	146,140	1.10	855	2.00	265,700
Chiropractors	12,370	1.00	12,370	1.18	14,600
Veterinarians	8,520	1.05	8,114	2.23	18,100
Podiatrists	5,050	1.00	5,050	2.00	10,100
TOTAL					431,570

[a] Report of State and Local Radiological Health Programs Fiscal year 1975 (51). Data for New Jersey estimated from 1974 and 1976 Reports. Therapeutic x-ray machines are included.
[b] Fess statistics on diagnostic x-ray utilization (61).
[c] Personnel resource data from the American College of Radiology (65).
[d] Includes units for physicians, clinics, and other (e.g., nursing homes).
[e] Radiology facilities must be subtracted from physicians' facilities, hence 56,730 divided by 1.16 equals 48,905 minus 4,656[c] equals 44,249.

There also would be potentially exposed workers for the 2,040 private practice licensees of the NRC and Agreement States. We believe that few, if any, of these licenses were assigned to dentists. Many would be held by radiology clinics; the remainder would be distributed among specialty and other large practice clinics. Using the 7.2 persons per facility found by Barrall and Smith (62), there would be 14,700 additional medical workers exposed to radiation. Thus, we projected that about 446,300 total medical workers are potentially exposed to radiation in private practices. This total is much smaller than the 773,000 workers projected solely from the commercial exposure data (Table B-1) and without benefit of professional manpower studies.

The combined total of the revised estimates for the hospital and private practice categories yielded about 545,000 persons, as opposed to the 930,000 based on projections from the commercial dosimetry service data. The Revised Code Method total is similar to a recent FDA estimate of the number of medical radiation workers (559,000) in 1978 (66).

The largest discrepancy between unrevised and revised Code Method worker projections occured in dentistry. The Fess data gave two exposed workers per x-ray facility whereas the commercial data yielded approximately four. The extrapolated number of dental personnel from these two estimates was 265,700 and 513,590, respectively. According to Fess, there was an average of 1.10 dental x-ray machines per facility and 1.09 machines per practitioner (61). This indicates that most facilities are solo practices where either the dentist or dental assistant takes the radiographs. We would expect, therefore, that in the average dental practice only two people are occupationally exposed to radiation.

The assumption of two radiation workers per dental facility is supported by another study of health personnel resources which identified 3,148 dentists practicing in 715 dental groups (67). The study showed that in 1973, on average, approximately two auxiliary persons were employed for each dentist in these group practices. Only 1.5% of these auxiliaries were designated as x-ray technicians; 61% were dental assistants and hygienists; and the remaining 37.5% were primarily secretarial and receptionist support. Thus, even in group practices, there are likely just two and at most three persons potentially exposed per dentist, including the dentist.

2. Academic

The estimate of potentially exposed workers for the academic group in Table B-1 included students. Our only revision here to the original Code Method estimates was to eliminate grade schools, high schools and private preparatory schools. However, neither the revised Code Method nor the revised List Method provided a satisfactory approach to the Education category. Therefore, we made a separate analysis of education data (Appendix C) for the 1975 Exposure Summary given in Table 8.

3. Government

The principal change in the Government grouping for the revised Code Method was to combine some Federal Summaries data with code projections for other Federal, state, and local governments. The latter projection of 8,280 persons was added to the estimated 7,000 persons of the Veterans Admininstration to give a total of 15,300 workers. The exposure statistics for Government Research and Development came from the DOE (see Appendix D). Data for U.S. Army, Navy, Air Force and Department of Energy personnel and contractors came entirely from exposure summaries compiled by these agencies. These data covered all occupational exposure activities, including research and medical.

4. Industry

The "Industry" group of the commercial dosimetry data contained 22 separate codes and comprised about 15% of all customer institutions and 18% of the number of monitored workers. However, data for the 22 codes could not be exploited, since the number of NRC and NRC Agreement State licensees was known only for the Industrial Radiography code. We treated this subgroup separately by assuming that there were twice as many x-ray radiography facilities as there were NRC radiography licenses.

The commercial exposure data for the remaining 21 industry codes were combined and assumed to be a representative sample for the entire Industry group. We added the number of all other NRC and NRC Agreement State industrial licensees to the number of non-medical x-ray and accelerator facilities to obtain an upper estimate of the total number of remaining "Industry" facilities. We assumed that each accelerator or x-ray unit represented a facility. The total number of workers projected for "Other Industrial" and "Manufacturing and Distribution" categories was 196,240. The Services group from the initial Code Method provided the remaining entry in the Industry category. We eliminated the Insurance subgroup from this group, since the estimated exposure per person was less than 1 mrem.

5. Nuclear Fuel Cycle

We placed the utilities group of the intial Code Method in the Uranium Fuel Cycle group, since it is basically documented by the NRC. The NRC maintains complete summary data for nuclear power plants and nuclear fuel sources and reprocessing. The subcategory of Uranium Enrichment is documented by the DOE.

IV. REVISED CODE METHOD RESULTS

The Occupational Exposure Summary for 1975 that we estimated with the revised Code Method is given in Table B-3. Five major occupational categories were used: MEDICINE, INDUSTRY, NUCLEAR FUEL CYCLE, GOVERNMENT, and EDUCATION.

We could not make estimates for nuclear waste disposal and uranium mills in the Code Method. However, we estimated only 600 persons and 8 person-rems in the List Method for these two activities.

The extrapolated work force and collective dose determined by the revised Code Method were, respectively, 12% and 8% less than the corresponding values from the revised List Method. This is primarily due to the substantially reduced number of estimated workers in the medical and educational categories. Since these two categories have lower mean exposures than the entire work force average, the percentage decrease in collective dose is less than the percentage decrease in work force. Consequently, the overall average doses for the "total" and "exposed" populations increases slightly.

Table B-3.
REVISED CODE METHOD
OCCUPATIONAL EXPOSURE SUMMARY FOR 1975

Category	Extrapolated Population[a]		Mean Whole-Body Dose[b] (millirem)		Collective Dose[c] (person-rems)
	Total	Exposed	Total	Exposed	
MEDICINE:					
Hospital/Clinic Radionuclide & Electronic Sources	100,000	55,100	220	400	22,000
Private Practice Radionuclide & Electronic Sources	137,800	53,300	160	410	21,700
Dental	265,700	41,400	20	140	5,800
Podiatry	10,100	2,100	10	30	100
Chiropractic	14,600	3,700	30	110	400
Veterinary	18,100	6,200	80	230	1,400
SUBTOTAL	546,300	161,800	90	320	51,400
INDUSTRY:					
Industrial Radiography Radionuclide & Electronic Sources	17,890	10,200	550	960	9,800
Other Industrial Radionuclide & Electronic Sources AND Manufacturing & Distr. Radionuclide & Electronic Sources	196,240	48,510	80	330	15,900
Services	40,490	9,720	60	270	2,600
SUBTOTAL	254,600	68,400	110	410	28,300
NUCLEAR FUEL CYCLE:					
Nuclear Pwr Reactors	54,763	28,034	390	760	21,400
Nuclear Fuel Fabrication & Reproc'g	11,405	5,495	270	560	3,100
Nuclear Waste Disp. Uranium Mills	(Extrapolations not feasible)				

Table B-3. (Continued)

Category	Extrapolated Population[a] Total	Extrapolated Population[a] Exposed	Mean Whole-Body Dose[b] (millirem) Total	Mean Whole-Body Dose[b] (millirem) Exposed	Collective Dose[c] (person-rems)
Uranium Enrichment	7,471	5,664	50	70	400
SUBTOTAL	73,600	39,200	340	630	24,800
GOVERNMENT:					
Government Radionuclide & Electronic Sources	15,300	4,420	120	400	1,800
Military	92,500	55,800	110	180	10,100
Res. & Dev.	80,954	39,451	150	300	11,800
SUBTOTAL	188,800	99,700	130	240	23,600
EDUCATION:					
Radionuclide & Electronic Sources	56,440	17,200	70	240	4,100
TOTAL	1,119,800	386,300	120	340	132,200

[a] The left column is the estimated total number of potentially exposed individuals in each activity. The right column is the estimated number of individuals who received a measureable dose. The Total and Subtotal values are rounded to the nearest 100 persons.

[b] The mean doses correspond to the populations in the first two columns. The mean dose for those exposed is the quotient of the collective dose and the extrapolated exposed population. Mean doses are rounded to the nearest 10 mrem.

[c] The collective dose is the product of the extrapolated total population and the corresponding mean dose. Collective doses are rounded to the nearest 100 person-rem.

APPENDIX C

ANALYSES OF MISCELLANEOUS CATEGORIES AND ADDITIONAL GROUPS

I. EDUCATION DATA C-3

  A. Students C-3

  B. Faculty and Staff C-5

II. TRANSPORTATION C-7

LIST OF TABLES

Table	Title	Page
C-1	Annual Number of Students Enrolled in Radiation Related Courses	C-4
C-2	Faculty Work Force	C-6
C-3	Occupational Exposures Resulting from Transport of Radioactive Materials	C-8

I. EDUCATION DATA

We revised the education data because both the List and Code Methods included students in the education work force. In general, students are not considered radiation workers. We decided that the education contribution to the radiation work force should include only faculty members, radiation safety officers, and certain students (i.e., those reimbursed for duties involving radiation outside the normal scope of their curriculum--for example, teaching assistants and research grant participants). Students are therefore shown separately in Table 8 under ADDITIONAL GROUPS.

A. Students

Students are potentially exposed to radiation in courses in medical and medico-technical schools and in some courses in liberal arts universities (includes colleges). Data for medical school enrollment taken from the report "Institutional Characteristics of U.S. Medical Schools 1975-1976" (68) are shown in Table C-1. We assumed that undergraduate and graduate students in medical programs enrolled in courses having radiation exposure potential 30% of the time. Therefore, the annual number of potentially exposed medical students was about 43,300.

For universities, we assumed that the number of Bachelors degree recipients in science fields in any year represented 13% of the undergraduate students in these fields, since the national average for all disciplines was 13% (69). We assumed that all students enrolled in the

Table C-1. ANNUAL NUMBER OF STUDENTS ENROLLED IN RADIATION RELATED COURSES*

Educational Program	Total Students Under-graduate	Total Students Graduate	Total	Estimated Potentially Exposed Students Under-graduate	Estimated Potentially Exposed Students Graduate	Estimated Potentially Exposed Students Total
MEDICAL						
MD	51,000	35,000	86,100			
Dentistry	19,400	13,300	32,700			
Veterinary	6,000	4,100	10,100			
Chiropractic	4,700	3,200	7,900			
Osteopathy	2,800	1,900	4,700			
Podiatry	1,800	1,200	3,000			
Subtotal	85,800	58,700	144,500	25,700[a]	17,600[a]	43,300
UNIVERSITY	Under-graduate[b]	Graduate[c]	Total			
Nuclear Engineer	3,200	2,100				
Rad. Technician	2,000	200				
Nuclear Physics	700	100				
Dental Specialist	600	1,400				
Radiobiology	0	100				
Subtotal	6,500	3,900	10,400	6,500	3,900	10,400
General Physics	2,600[d]	1,100				
General Chemistry	4,200	700				
Subtotal	6,800	1,800	8,600	2,000[a]	500[a]	2,500
MEDICAL TECHNICAL						
Dental Assistant	8,700	-	8,700			
Dental Hygienist	9,500	-	9,500			
Radiological Tech.	16,800	-	16,800			
Subtotal	35,000		35,000	35,000		35,000
TOTAL	134,100	64,400	198,500	69,200	22,000	91,200

---

[a] Assume 30% of students enroll in radiation related course in any year.
[b] Assume B.S. graduates represent 13% of all undergraduate students.
[c] Assume M.S. and Ph.D. graduates represent 20% of all graduate students.
[d] Assume 10% of Physics majors enroll in radiation courses 30% of the time.
[e] Assume 5% of Chemistry majors enroll in radiation courses 30% of the time.

*Based on data from "Digest of Education Statistics 1977-78," (69).

first five university disciplines listed in Table C-1 were potentially exposed each year. We assumed that only 10% of Physics majors and 5% of Chemistry majors were enrolled in courses involving radiation each year. The total number of potentially exposed undergraduate and graduate students at universities was 12,900.

We assumed that all students at medico-technical schools were potentially exposed each year of their two-year programs (70). We assumed there were no graduate students at these facilities. The total number for these medico-technical school students was 35,000.

The total number of potentially exposed students for the so-called four-year (medical and university) and two-year institutions were 56,200 and 35,000, respectively. We used the average dose determined in the Code Method (Table B-1) for students in the National Summary (Table 8).

B. Faculty and Staff

We arbitrarily assigned faculty/staff and student/faculty ratios for the different type educational institutions. Based on the student population given in Table C-1, the number of faculty and staff were determined to be approximately 7,000 for two-year institutions and 14,800 for four-year institutions, for a total of 21,800 workers (see Table C-2). We used the average dose determined in the Code Method (Table B-1) for the Faculty entry in the National Summary (Table 8).

Table C-2. FACULTY WORK FORCE INVOLVED IN RADIATION-RELATED PROGRAMS

	Educational Institution		
	Medical	University	Technical Medical
Undergraduate Students	25,700	8,500	35,000
Student/Faculty Ratio	10:1	20:1	10:1
Undergraduate Faculty	2,570	430	3,500
Graduate Students	17,600	4,400	--
Student/Faculty Ratio	5:1	10:1	--
Graduate Faculty	3,520	440	--
Faculty Subtotal	6,090	870	3,500
Associated Staff/Faculty Ratio	1:1	2:1	1:1
Associated Staff	6,090	1,740	3,500
Faculty & Staff Subtotal	12,180	2,610	7,000
TOTAL Faculty Work Force	21,800		

II. TRANSPORTATION

Transportation was the second entry in the MISCELLANEOUS category. Many radioactive material shipments are low in radioactivity and do not require licensed shippers and handlers. Thus, not all radioactive material transport firms appear on NRC licensee lists. Some data were available from the Code Method, but these did not agree well with estimates from NRC's Final Environmental Statement on the Transport of Radioactive Materials by Air and Other Modes (NUREG-0170) (71). This NRC report provided dose data but not work force figures, so we roughly estimated the latter (Table C-3).

The first column of Table C-3 shows the estimated number of potentially exposed crew and handlers associated with each transport mode. We derived these worker estimates by dividing collective dose estimates by corresponding estimated average doses. For the passenger aircraft transport mode, the estimated average dose of 10 mrem/yr was taken from NUREG-0154 (72). The average doses for Truck, Rail and Secondary Modes, and Other Transport Modes, relied on the NUREG-0170 report. We estimated about 77,000 persons in this work-force. See MISCELLANEOUS Subgroup in Table 8.

We separately estimated that there were about 30,000 airline flight attendants (pilots not included) who potentially receive extremely low average doses from radioactive material on passenger aircraft. Exposure to cosmic radiation was not included. We assumed that the ratio of potentially-to-measurably exposed workers was 3 to 1, the same as for the entire radiation work force. See ADDITIONAL GROUPS entry in Table 8.

Table C-3. OCCUPATIONAL EXPOSURES RESULTING FROM TRANSPORT OF RADIOACTIVE MATERIALS

Transport Mode	Potentially Exposed Work Force (Crew and Handlers)	Estimated Mean Annual Dose (millirem)	Estimated Collective Dose[a] (person-rems)
Passenger and Cargo Aircraft	47,000	10[b]	470
Truck	15,000	70	1,050
Rail	4,000	25	100
Other	1,000	10	10
Secondary Modes	10,000	70	700
Subtotal	77,000	30	2,330
Passenger Aircraft (Flight Attendants)	30,000	3	100[c]
TOTAL	107,000	20	2,430

---

[a] Source: NUREG - 0170, (72).
[b] Source: NUREG - 0154, (73).
[c] Excludes dose from cosmic radiation.

APPENDIX D

TABULATED SUMMARIES FROM FEDERAL AGENCIES

LIST OF TABLES

Table	Title	Page
D-1	U.S. Air Force Exposure Data	D-2
D-2	Army Personnel Monitored During the Calendar Year 1975	D-4
D-3	Bureau of Radiological Health, 1975 Exposure Data by Age	D-5
D-4	Distribution of Annual Whole-Body Exposures for All ERDA Employees 1975	D-6
D-5	National Aeronautic and Space Administration Data	D-7
D-6	National Bureau of Standards Personnel Monitored During the Calendar Year 1975	D-8
D-7	Statistical Analysis of Navy Radiation Exposure Data for Calendar year 1975	D-9
D-8	National Institutes of Health (NIH) Repository Data 1975	D-10
D-9	Nuclear Regulatory Commission Repository Data	D-11
D-10	Uranium Miner Exposures	D-12
D-11	U.S. Naval Shipyard Exposure Data	D-13
D-12	Radiation Exposure Information in U.S. Navy BUMED System	D-14

Table D-1. U.S. AIR FORCE EXPOSURE DATA

SUMMARY OF IONIZING RADIATION EXPOSURE FOR CALENDAR YEAR 1975
AS COMPILED FROM THE USAF MASTER RADIATION REPOSITORY
USAF OEHL BROOKS AFB TX OCTOBER 1979

NUMBER OF INDIVIDIUALS IN EXPOSURE GROUP
(MILLIREM PER YEAR WHOLE-BODY)

OCCUPATIONAL CATEGORY	0-20	21-50	51-100	101-250	251-500	501-1000	1001-5000	MORE THAN 5000
MEDICAL MAINT.	364	29	15	12	3	-	-	-
X-RAY TECHNICIAN	1614	116	49	31	5	1	1	-
RADIOLOGIST	170	13	5	6	2	-	1	-
MEDICAL MISC.	1279	94	46	18	4	1	-	-
DENTAL	3181	203	139	54	8	1	-	1
VETERINARY	329	29	13	5	-	-	-	-
PHYSICIAN NUCLEAR MED.	29	1	2	-	-	-	-	-
TECHNICIAN NUCLEAR MED.	180	9	8	2	-	-	-	-
PMEL	1345	85	55	28	2	-	-	-
INDUSTRIAL RADIOISOTOPES	212	17	8	5	1	-	-	-
INDUSTRIAL X-RAY	1875	124	77	45	4	1	-	-
RADAR	293	20	16	10	2	-	-	-
SPECIAL WEAPONS	538	26	21	12	2	-	1	-
NUCLEAR REACTORS	2	-	-	-	-	-	-	-
RAD. MISC.	214	18	8	7	1	-	-	-
AF CONTRACTORS	33	-	4	1	-	-	-	-
RADIOACTIVE WASTE DISPOSAL	1	-	-	-	-	-	-	-
MAINT. MISC.	489	31	27	14	1	-	-	-
DISASTER	371	24	11	5	2	1	-	-
HEALTH PHYSICS	424	32	10	3	1	1	-	-
ALL OTHER	1305	70	64	28	3	1	-	-
TOTALS	14248	941	578	286	41	7	3	1

Table D-2. ARMY PERSONNEL ANNUAL EXPOSURE DATA FOR THE CALENDAR YEAR 1975*

Whole-Body Exposure Range (rem)	Number of Personnel	Collective Dose (person-rems)
No Measurable Exposure	9310	0
Meas. Exp. Thru 0.099	5932	117.5
0.100 Thru 0.249	414	64.2
0.250 Thru 0.499	171	67.9
0.500 Thru 0.749	75	46.5
0.750 Thru 0.999	24	21.6
1.000 Thru 1.999	30	40.1
2.000 Thru 2.999	6	14.5
3.000 Thru 3.999	2	6.3
4.000 Thru 4.999	1	4.2
5.000 Thru 5.999	0	0
6.000 Thru 6.999	2	13.4
7.000 Thru 7.999	1	7.0
8.000 Thru 8.999	1	8.1
9.000 Thru 9.999	0	0
10.000 Thru 10.999	1	10.4
11.000 Thru 11.999	0	0
12.000+	0	0

---

*Private communication from Col. Robert Wangemann, Feb. 8, 1980.

Table D-3. BUREAU OF RADIOLOGICAL HEALTH, 1975 EXPOSURE DATA BY AGE

NUMBER OF PERSONS MONITORED BY ANNUAL EXPOSURE RANGE AND AGE GROUPINGS

AGE RANGE	10 (mrem)	10-99 (mrem)	100-249 (mrem)	250-499 (mrem)	500-749 (mrem)	750-999 (mrem)	1000+ (mrem)	TOTAL
UNDER 18	1	3	1					5
18 - 19		4						4
20 - 24	92	98	13	1	1			205
25 - 29	200	272	17	1	1	1	1	493
30 - 34	209	280	38	7	2	1	2	539
35 - 39	136	185	22	6	2		2	353
40 - 44	100	119	19	5		1	1	245
45 - 49	67	102	17	7	1			194
50 - 54	35	87	12					134
55 - 59	24	55	5	1				85
60-64	10	16		1	1			28
65 AND OVER	37	65	4	1				107
TOTALS	911	1286	148	30	8	3	6	2392

Table D-4. DISTRIBUTION OF ANNUAL WHOLE-BODY EXPOSURES FOR ALL ERDA EMPLOYEES 1975

EXPOSURE RANGES (REMS)

FACILITY TYPE	TOTAL MONITR	< MEAS.	<0.10	0.10 0.25	0.25 0.50	0.50 0.75	0.74 1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12+	TOTAL Person-Rems
REACTOR 1800	3812	1082	882	427	427	258	146	299	238	50	3									
FUEL FAD	1050	74	519	190	155	55	27	25	5											225
FUEL PROC	1865	285	619	245	224	140	108	170	61	13										793
URAN ENRCH	7471	1807	5236	282	105	29	6													383
WEAPON FET	19425	11579	4365	2341	594	224	113	181	24	4										1435
IRRAD FACL																				
GEN RESRCH	33769	19430	9242	2453	1184	510	330	484	118	14	3			1						3034
ACCELERATR	7384	5002	1161	446	247	135	79	177	72	46	18		1							1076
OTHER	11479	2340	6055	876	651	343	253	503	235	106	117									3375
VISITORS	58946	54190	3764	750	157	40	20	21	4											462
ERDA OFFCS	2170	1711	376	51	23	5	2	2												44
TOTAL	147371	97500	32219	8061	3767	1739	1084	1868	757	233	141		1	1						12627

Table D-5. NATIONAL AERONAUTIC AND SPACE ADMINISTRATION DATA

Distribution of Annual Whole Body Exposure*
1975

		Exposure Ranges (Rem)																
Covered Categories	Total No. Personnel Monitored	Less Than Measurable	Less Than 0.10	0.10 0.25	0.25 0.50	0.50 0.75	0.75 1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12.
Research Activities	1,410	1,136	205	48	8	7	5	1										

Distribution of Extremity Exposures
1975

		Exposure Ranges (Rem)																
Covered Categories	Total No. Personnel Monitored	Less Than Measurable	Less Than 0.10	0.10 0.25	0.25 0.50	0.50 0.75	0.75 1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12
	63	41	18	2			1	1										

*Astronaut exposures not included.

Table D-6. NATIONAL BUREAU OF STANDARDS PERSONNEL ANNUAL EXPOSURE DATA FOR THE CALENDAR YEAR 1975

Whole-Body Exposure Range (rem)	Number of Personnel	Collective Dóse (person-rems)
No Measurable Exposure	203	0
Meas. Exp. Thru 0.099	139	4.293
0.100 Thru 0.249	28	4.662
0.250 Thru 0.499	13	4.287
0.500 Thru 0.749	5	2.932
0.759 Thru 0.999	4	3.528
1.000 Thru 1.999	1	1.580
2.000 Thru 2.999	0	0
3.000 Thru 3.999	0	0
4.000 Thru 4.999	0	0

Table D-7. STATISTICAL ANALYSIS OF NAVY RADIATION EXPOSURE DATA FOR CALENDAR YEAR 1975

Exposure Range (rem)	Number of Records
.000-.099	43266
.100-.249	3961
.250-.499	2335
.500-.749	1104
.750-.999	660
1.000-1.999	1159
2.000-2.999	558
3.000-3.999	117
4.000-4.999	80
5.000-5.999	0
6.000-6.999	0
7.000-7.999	0
8.000-8.999	0
9.000-9.999	0
10.000-10.999	0
11.000-11.999	0
12.000+	0
Total Personnel Monitored	53240

Table D-8. NATIONAL INSTITUTES OF HEALTH (NIH) EXPOSURE DATA - 1975

Dose Range (rem)	Whole-Body Exposure (persons)	Extremity Exposure (persons)
Measurable	2,004	241
.10	130	46
.10 to .25	28	6
.25 to .50	7	1
.50 to .75	7	3
.75 - 1.00	3	0
1-2	2	1
2-3	1	2
3-4	1	1
Total Monitored	2,183	301

Table D-9. NUCLEAR REGULATORY COMMISSION REPOSITORY DATA

DISTRIBUTION OF ANNUAL WHOLE-BODY EXPOSURES
REPORTED BY COVERED LICENSEES - 1975

Covered Categories of NRC Licensees	Total No. Monitored	Exposure Ranges (Rem)																	
		Less than Measurable	Measurable - 0.10	0.10 -0.25	0.25 -0.50	0.50 -0.75	0.75 -1.00	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	>12
Power Reactors	54763	26729	10606	4081	2948	1778	1384	3982	1873	692	424	169	60	24	12	0	1	0	0
Industrial Radiography	9178	4485	1811	813	614	346	263	538	171	64	35	21	8	1	3	1	2	1	1
Fuel Processing & Fabrication	11405	5910	1968	1102	1021	433	241	381	153	77	40	30	11	9	14	15	0	0	0
Manufacturing & Distribution	3367	1508	644	532	241	88	67	140	65	43	39	11	12	3	0	1	0	0	0
Totals	78713	38632	15029	6528	4797	2645	1955	5041	2262	876	538	231	91	37	29	17	3	1	1

Table D-10. URANIUM MINER EXPOSURES

Total Employment	Average Exposure	Miners having exposure in indicated intervals, percent				
		0-1 WLM	1-2 WLM	2-3 WL,	3-4 WLM	4 WLM
3,344	1.07 WLM	56.5	23.5	12.4	6.1	1.4

Source: Mine Enforcement and Safety Administration, "Administration of the Federal Metal and Non-Metallic Mine Safety Act (P.L. 89-577), Annual Report of the Secretary of Interior - 1975."

Table D-11. U.S. NAVAL SHIPYARD EXPOSURE DATA*

	Number of Persons Monitored in Shipyards - By Year			Total Radiation in Shipyards (person-rems)		
	Navy Yards	Private Yards	Total	Navy Yards	Private Yards	Total
1978	10849	4135	14984	2714	966	3680
1977	10659	5064	15723	3728	1471	5199
1976	10208	4765	14973	3490	1820	5310
1975	10244	4419	14663	3820	1465	5285
1974	10101	5056	15157	4931	2275	7206
1973	9543	5799	15252	3826	2257	6083
1972	12886	7313	20199	4792	2210	7002
1971	15748	8177	23925	7328	3288	10616
1970	16489	9434	25923	6946	6138	13084
1969	16926	12744	29670	6776	4301	11077
1968	19727	13324	33051	6149	2570	8719
1967	21550	14084	35634	9730	4178	13908
1966	18946	17228	36174	11791	7013	18804
1965	13182	15025	28207	11135	4694	15829
1964	9560	16133	25693	3495	2183	5678
1963	7650	12252	19902	1821	904	2725
1962	6434	9486	15920	4631	591	5222
1961	2107	11626	13733	74	1167	1241
1960	1974	10394	12368	681	477	1158
1959	2816	8076	10892	1425	439	1864
1958	708	5290	5998	14	765	779
1957	0	3608	3608	0	495	495
1956	0	2862	2862	0	162	162
1955	0	2679	2679	0	344	344
1954	0	528	528	0	64	64

---

*Source: Private communication from W.R. Kindley, September 27, 1979

Table D-12. RADIATION EXPOSURE INFORMATION IN U.S. NAVY BUMED SYSTEM*

YEAR	TOTAL NUMBER OF PERSONNEL MONITORED	TOTAL MAN-REM
1960	12105	2,657
1961	15372	1,642
1962	21179	6,446
1963	28718	5,671
1964	35108	8,777
1965	40690	16,411
1966	49243	17,075
1967	56220	15,509
1968	55476	10,879
1969	54911	12,128
1970	51818	10,527
1971	54468	12,206
1972	56361	8,504
1973	51079	8,340
1974	54056	8,923
1975	55962	7,988
1976	55934	7,628
1977	57056	7,665

---

*Source: Communication from Vice Admiral W.P. Arentzen, Surgeon General of the Navy, January 22, 1979.

APPENDIX E

COMMERCIAL EXTREMITY DATA

LIST OF TABLES

Table	Title	Page
E-1	Distribution (Percent) of Commercial Sample Extremity Data by Dose Range	E-3

Table E-1. DISTRIBUTION (PERCENT) OF COMMERCIAL SAMPLE EXTREMITY DATA BY DOSE RANGE (REM)

Dose Range (rem)	Distribution (%)
Less than Measurable	49.1
Meas - 0.99	35.6
1.00 - 4.99	13.4
5.00 - 9.99	1.3
10.00 - 14.99	0.25
15.00 - 19.99	0.14
20.00 - 29.99	0.16
30.00 - 39.99	0.022
40.00 - 49.99	---
50.00+	0.045

Total Records in Sample - 13,382.

*U.S. GOVERNMENT PRINTING OFFICE:1981 341-082/148 1-3